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Measurements of Coefficients of Discharge for Concentric Flange-Tapped Square-Edged Orifice Meters in Natural Gas Over the Reynolds Number Range 25,000 to 16,000,000

James R. Whetstone, William G. Cleveland, Blaine R. Bateman,
and Charles F. Sindt

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James R. Whetstone, William G. Cleveland, Blaine R. Bateman, and Charles F. Sindt

Chemical Process Metrology Division
Center for Chemical Engineering
National Engineering Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899

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Measurements of Coefficients of Discharge for Concentric, Flange-Tapped, Square-Edged Orifice Meters in Natural Gas Over the Reynolds Number Range 25,000 to 16,000,000

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Blaine R. Bateman, Charles F. Sindt

Abstract

This report describes the data acquisition systems and procedures used in the American Petroleum Institute (API)-sponsored orifice discharge coefficient project performed in natural gas flows and conducted at the test loop of the Natural Gas Pipeline Company of America (NGPL) in Joliet, Illinois. These systems follow the general design philosophy of the companion intermediate Reynolds number project conducted in water flows [1]. NBS provided the measurement and data acquisition systems, maintained the resulting database, and calculated the results from that database.

Measurements of orifice discharge coefficients for 6- and 10-inch diameter orifice meter runs were made using critical venturis for mass flowrate measurement with associated measurement of pressures and temperatures. Eleven venturis were calibrated at the Colorado Engineering Experiment Station, Inc. (CEESI). Measurements of absolute and differential pressure and temperature for venturi and orifice meter conditions were made using an automated data acquisition system. Temperature and pressure measurements were directly related to U.S. national measurement standards. Daily calibration of absolute and differential pressure transducers using pressure working standards was designed into the measurement procedures.

Natural gas compositions were measured using on-line gas chromatography based on gravimetrically-prepared gas standards having compositions closely similar to those of the two gas stream compositions used. Calculations of natural gas density and viscosity were made using a recently developed state-of-the-art equation of state [2] and a corresponding-states model of transport properties [3].

Collected over a 2-year period, the database contains tests on 44 orifice plates in 8 beta ratios for two meter sizes (6- and 10-inches). The database contains 1,345 valid test points.

NOTE: On August 23, 1988 with the signing of the Omnibus Trade and Competitiveness Act, the National Bureau of Standards (NBS) became the National Institute of Standards and Technology (NIST). Since this report was written and reviewed before this change, references to NBS in the body of the report have not been changed to NIST.

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List of Symbols Used in Mathematical Formulas

a - area thermal coefficient for the ceramic ball/stainless nozzle combination of the deadweight tester

A_b - area of the ball of a deadweight tester

A_1 - area of the meter tube

A_2 - area of the orifice

A_t - nozzle throat area

C^* - critical factor for gas flowing through a critical nozzle

C_d - discharge coefficient, orifice or nozzle depending on context

c_p - specific heat of fluid at constant pressure,

c_v - specific heat of fluid at constant volume,

d - diameter of the orifice or nozzle depending upon the context

d_o - diameter of a nozzle during calibration

d_w - density of the weight material of a mass standard

D - the diameter of the meter tube

F_a - orifice thermal expansion factor

F_1 - diametral thermal expansion factor

g - acceleration of gravity

G_t - mass flow rate per unit area

H_p - nozzle plenum enthalpy

h - enthalpy of the flowing fluid per unit mass,

H_t - nozzle throat enthalpy

$\dot{m}$ - mass flow rate

m_1 - mass flow rate in the meter tube

m_2 - mass flow rate through the orifice

m_3 - theoretical mass flow rate

M - observed mass value

M_a - apparent mass of the weight stack on deadweight tester

M_t - true mass of the weight stack

N - a constant whose value depends upon the units of the measured parameters

P - pressure in the general case

P_1 - total pressure at the upstream orifice tap

P_2 - total pressure at the downstream orifice tap

P_p - nozzle plenum absolute pressure

R - universal gas constant, also resistance in ohms of a platinum resistance thermometer

R_D - pipe Reynolds number

R_d - nozzle throat Reynolds number

r - P_1/P_2, the ratio of the pressure at the downstream pressure tap to that at the upstream pressure tap,

s - entropy of the flowing fluid per unit mass,

s_{C_d} - total relative uncertainty in the orifice discharge

$s_{C_d f}$ - residual standard deviation of the fit for the nozzle discharge coefficient divided by the discharge coefficient in percent coefficient expressed in percent

$s_{C_d r}$ - random uncertainty in the orifice or nozzle discharge coefficient in percent

$s_{C_d s}$ - systematic uncertainty in the orifice or nozzle discharge coefficient in percent

s_{C^*} - relative uncertainty in the critical flow factor in percent

$s_{C^*_r}$ - random uncertainty in the nozzle plenum pressure in percent

$s_{C^*_s}$ - systematic uncertainty in the nozzle plenum pressure in percent

s_{jr} - random uncertainty in percent for the jth parameter relative to that parameter

s_{js} - systematic uncertainty in percent for the jth parameter relative to that parameter

$s_{\dot{m}}$ - relative uncertainty in the nozzle mass flow rate value in percent

$s_{\dot{m}r}$ - random uncertainty in the total mass flow rate in the system in percent

$s_{\dot{m}s}$ - systematic uncertainty in the total mass flow rate in the system in percent

s_{NA} - systematic nozzle area uncertainty

s_P - relative uncertainty in the nozzle pressure value in percent

s_{Pc} - uncertainty in the difference pressure applied to the transducers

s_{Pf} - residual standard of the fit for a static pressure transducer

s_{Pm} - standard deviation of the mean static pressure value taken during a test run

s_{Pr} - random uncertainty in the nozzle plenum pressure in percent

s_{Ps} - systematic uncertainty in the nozzle plenum pressure in percent

s_T - relative uncertainty in the temperature in percent

s_{Tm} - standard deviation of the mean temperature divided by the mean temperature in percent

s_{Tr} - random uncertainty in the nozzle plenum temperature in percent

s_{Ts} - systematic uncertainty in the nozzle plenum temperature in percent

$s_{\rho r}$ - random uncertainty in the gas density at the orifice conditions in percent

$s_{\rho s}$ - systematic uncertainty in the gas density at the orifice conditions in percent

$s_{\Delta Pf}$ - residual standard deviation of the fit for a differential pressure transducer

$s_{\Delta Pm}$ - standard deviation of the mean of a set of differential pressure observations taken during a test run

$s_{\Delta Pr}$ - random uncertainty in the differential pressure in percent

$s_{\Delta Ps}$ - systematic uncertainty in the differential pressure in percent

s_w - uncertainty in the mass standards

S_p - nozzle plenum entropy

S_t - nozzle throat entropy

$s_{x_j r}$ - random uncertainty in the nozzle plenum pressure in percent

$s_{x_j s}$ - systematic uncertainty in the nozzle plenum pressure in percent

T - temperature generally, may be absolute depending upon context

T_a - temperature of air

T_p - nozzle plenum absolute temperature

T_t - nozzle throat absolute temperature

u - internal energy of the flowing fluid per unit mass

u_t - sonic velocity of the gas in the throat of a nozzle

V - Ruska transducer voltage

V_o - Ruska transducer voltage at zero differential pressure

V_1, V_2 - velocity of the flowing fluid

Y - adiabatic expansion factor

W - tare force of the deadweight tester

Z - compressibility factor

α - coefficient of thermal expansion of a nozzle

β - d/D, the orifice beta ratio,

γ - c_p/c_V, the ratio of specific heats,

ΔP - $P^1 - P_2$, the differential pressure developed across the orifice meter.

ΔS - change in entropy

ΔH - change in enthalpy

ρ_1 - density of the fluid flowing in the meter tube,

ρ_2 - density of the fluid flowing in the orifice,

ρ_t - density of the fluid flowing in the nozzle throat,

μ - absolute viscosity

Measurements of Coefficients of Discharge for Concentric, Flange-Tapped, Square-Edged Orifice Meters in Natural Gas Over the Reynolds Number Range 25,000 to 16,000,000

I. Introduction

For the last two decades it has been recognized in the flowmetering community that a need exists for well-documented, experimental databases of coefficients of discharge for orifice meters in order to achieve a greater degree of accuracy in custody transfer measurements. The American Petroleum Institute (API) and the American Gas Association (AGA) made an initial attempt to resolve the situation for flange-tapped orifice meters in the mid-1970's; however, this attempt did not come to fruition. A subsequent effort was made by API and the Gas Processors Association (GPA) to develop a comprehensive and well-documented database of discharge coefficients for flange-tapped orifice meters spanning their range of use. The three major parameters to be varied were the Reynolds number, the meter tube diameter, and the ratio of the orifice diameter to the pipe diameter (known as the beta ratio). To accomplish this objective a program consisting of three projects was planned. Common to the program would be a set of orifice meters comprised of meter tubes in five sizes with each size having sets of seven orifice plates with a beta ratio range from 0.1 to 0.75. Each project would concentrate on one region of the Reynolds number range by using a particular fluid for flow tests. The fluids were selected on a practical basis, and the three projects were designed so that data developed by any one project would overlap that developed by a companion project in the adjacent Reynolds range. The low Reynolds number project would be performed using a moderate viscosity liquid and the smaller diameter orifice meters. The intermediate Reynolds number project would use water as the test fluid and would involve all orifice meters. The high Reynolds number project reported here would use natural gas and the larger orifice meters.

The high Reynolds number project differed from the other two projects in that the API entered into two contractual agreements to perform the work. In 1983 the U.S. National Bureau of Standards (NBS) and the API agreed that NBS (1) would supply a documented measurement system for use in the high Reynolds number project, (2) would reduce the data derived from the test observations, and (3) would supply that data to API and make it part of the public domain. The flow testing site was that of the Natural Gas Pipeline Company of America (NGPL) located near Joliet, IL. NGPL was responsible for the day-to-day operation of the tests and provided the critical venturis and their calibration for use as the mass flow rate measurement standards. Funded by the Gas Research Institute, the Colorado Engineering Experiment Station, Inc. (CEESI) performed the calibrations of the critical venturis.

This report describes the measurement systems provided by NBS, the operation of the tests, the flow control and measurement system (in sufficient detail to discuss the results of the testing program), and the results of the testing program. The approach taken by NBS was to document the measurement procedures and standards and relate them to

U.S. national standards maintained by NBS for all of the measured parameters except mass flow rate.

As with any database development or research project, a set of initial assumptions and conditions are necessary to form the basic framework within which the project operates and its goals are accomplished. The following is written to describe this framework. During the course of the project some of the specific conditions, procedures and methods changed. However, the basic framework and objective of the project remained essentially constant.

The rationale for the configurations of the orifice meters and the measurement system was the following:

- A primary condition of the project was that it would develop a fundamental discharge coefficient database. Effects on the orifice meter from a variety of extraneous sources not associated with the fundamental orifice meter configuration were to be eliminated or their effect minimized.

- Two orifice meter sizes were used in this project. These had nominal diameters of 6 and 10 inches[a]. In each size a single level of redundancy would be realized, i.e., two meter tubes at each size would comprise a meter tube assembly. Flange taps would be used to reflect the preponderance of U.S. commercial practice.

- Each meter tube size would have two sets of orifice plates having beta ratios ranging from nominally 0.1 to 0.75. Each set would be nominally identical in a particular size and each set was used with a single meter tube with one exception.

- The manufactured quality of the meter tubes and orifice plates was to be of commercial quality in order to reflect a level of variability normally seen in commercial metering installations. Therefore, the meter tubes were constructed of seamless steel tubing, and fitted with ANSI 600 psi steel flanges. However, a departure from commercial practice was made in the types of flange seals. Rather than the compression gasket seals normally used in commercial orifice metering, o-ring seals were used. The o-ring grooves were placed in each interior flange of the three section meter tube set. The use of o-ring seals provided a reproducible method for locating the pressure taps relative to the orifice plate. This also eliminated any step in the diameter between the meter tube and the orifice, and eliminated the question of the effect of gaskets of variable thickness and diameter on the discharge coefficients calculated from the database.

- The maximum differential pressure would be approximately 200 inches of water or 7.5 psid. The minimum differential pressure would be determined by the capability of the measurement system.

To conform with the sponsor's request, English units are used throughout this report. This procedure departs from the normal NBS practice of using SI units in its technical publications.

- Where feasible, state-of-the-art measurement techniques would be employed.

- All measured parameters were to be referred directly to U.S. standards of measurements.

- Documentation of the measurement systems and procedures was to be as complete as possible.

- In an attempt to isolate the orifice meter from effects caused by the installation of the orifice meters in the test facility, a flow conditioner and an approach tube (approximately 40 diameters long) were added to the normal commercial meter tube configuration.

In planning this project it was decided that the amount of data acquired manually would be minimized. In particular, all pressure and temperature measurements would be automated to minimize human error. As a consequence, the rate at which differential pressure values could be acquired was much larger than in previously reported work, and each of these values was recorded on magnetic media. Therefore, the database that has resulted from this project is quite voluminous and cannot be included in its entirety in this report. Omitted from this report are the observations of each differential pressure, static pressure, and temperature recorded for each test run by the data acquisition system. However, the entire database is available in computer-readable form. The structures of the database are given here and the database itself is available from the API.

Computations of the results of the tests are closely related to the calculation of the physical properties of natural gas. A state-of-the-art equation of state for natural gas [2] and a state-of-the-art program for computing transport properties [3] were used in computing the final results. Results for the test runs taken during the summer and fall of 1984 and 1985 are included in the report. Excluded from these results are those runs made invalid by operator error or measurement equipment malfunction.

This report has been written with several objectives. In addition to the need to report the data and results accurately, considerable effort has gone into the presentation of the procedures and methods used in acquisition of the observational database. A primary objective in planning and executing the project was to fully document the work in such a way that those interested in evaluating the basis for the project's results could do so to a level of detail similar to that used in its execution. The driving force behind this requirement has been the lack of detailed descriptions of the previous work [4] upon which presently used correlations [5,6] of orifice discharge coefficients are based. To a large extent the justification for the orifice meter database program, of which this project is a part, is the lack of such information in the current world database. Therefore, this report has been written with considerable detail so that future workers in the field may profit from it.

II. Experimental Facilities and Measurement Systems

The tests were conducted using the Natural Gas Pipeline Company of America's (NGPL) natural gas test loop located at their Joliet, IL station. A description of this facility written by the NGPL Principal Investigator for this project, Mr. G. G. Less, is given in Appendix A. Excerpts from that report are given here to clarify the descriptions of the experimental configurations and procedures.

NGPL's Joliet station is located at the junction of two major natural gas transmission lines as shown in figure 1. One supplies natural gas produced along the U.S. gulf coast; this will be designated Gulf Coast Gas. The other originates near and supplies natural gas produced in the Texas panhandle region near Amarillo, TX; this will be designated Amarillo Gas. The compositions of the two sources of natural gas differ significantly in methane and nitrogen content. Typical analyses of the compositions taken from two test runs are given in table 1. Variations in the gas compositions of each stream were considerably smaller than the between-stream differences.

Table 1. Typical compositions of the gulf coast and Amarillo natural gas sources

Gas Component	Gulf Coast Gas Mole Percent	Amarillo Gas Mole Percent
Methane	95.966	90.639
Ethane	2.092	4.566
Propane	0.472	0.824
I-Butane	0.105	0.103
N-Butane	0.102	0.147
I-Pentane	0.046	0.040
N-Pentane	0.028	0.034
C6 Plus	0.065	0.039
Nitrogen	0.347	3.136
Carbon dioxide	0.776	0.472

The natural gas test loop was installed in parallel with NGPL's mainline regulators such that the natural gas from either source could pass through the loop. The test loop was arranged such that inlet gas pressures from 450 to 750 psig and outlet pressures from 385 to 415 psig were available. This arrangement allowed the use of critical-flow venturis as flow measurement standards. For the series of tests reported here, the test loop was modified to include multiple nozzle manifolds which allowed flow rates to be changed quickly without removal of nozzles from the system. A shed containing an instrumentation and control room was added to house the computer and data logging equipment, the pressure measurement standards and transducers, and the gas chromatograph and associated bottles of calibration gas. The remainder of this section deals with the systems used to measure temperature,

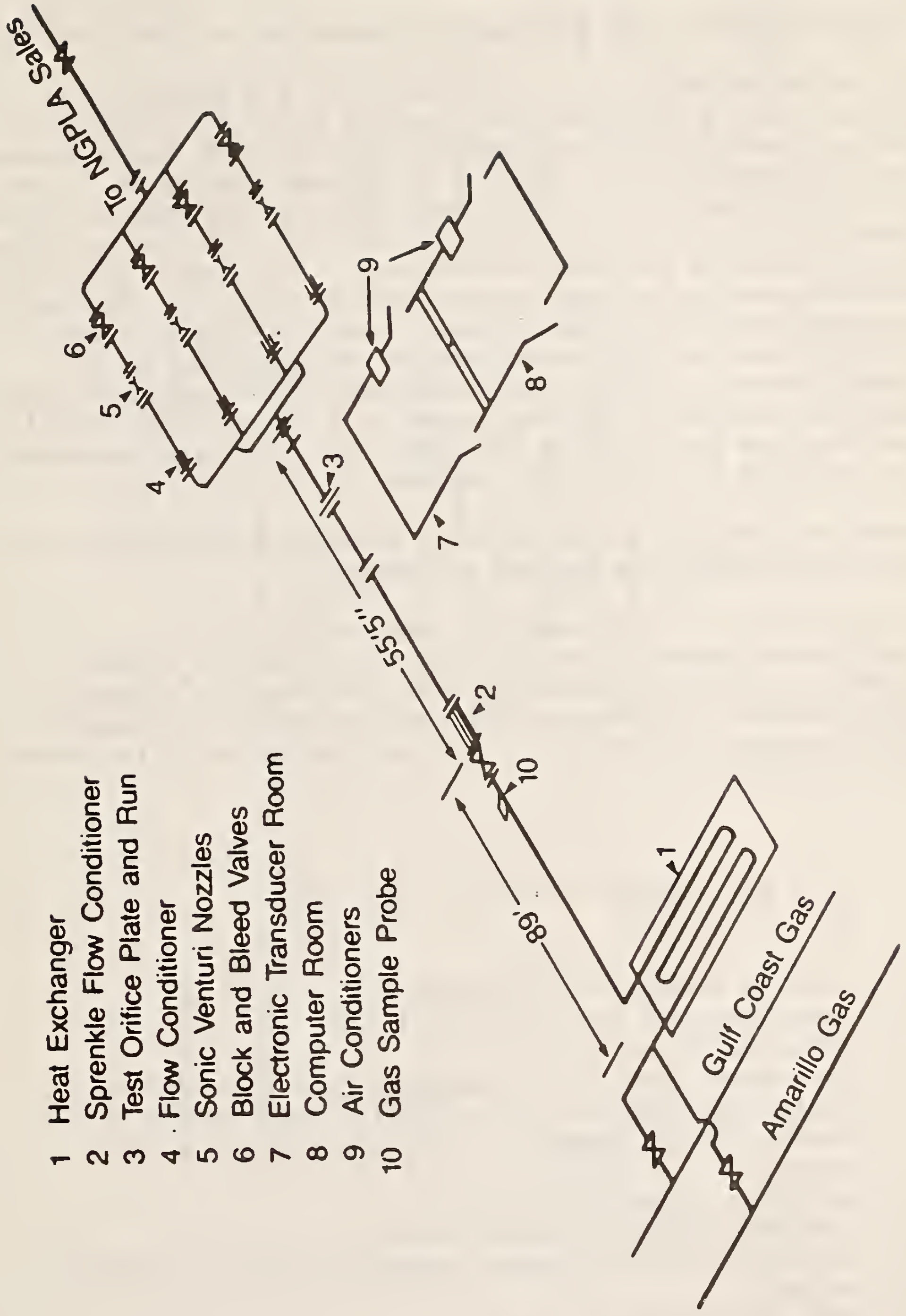

1 Heat Exchanger
2 Sprenkle Flow Conditioner
3 Test Orifice Plate and Run
4 Flow Conditioner
5 Sonic Venturi Nozzles
6 Block and Bleed Valves
7 Electronic Transducer Room
8 Computer Room
9 Air Conditioners
10 Gas Sample Probe
To NGPLA Sales
6
5
4
3
9
9
8
7
55'5"
2
10
1
68'
Gulf Coast Gas
Amarillo Gas

Figure 1. Schematic diagram of the natural gas test loop's major components

pressure, gas composition, and mass flow rate. These parameters form the basic database from which orifice discharge coefficients are calculated. From these, we develop a method to calculate the uncertainty in the discharge coefficients for each test run.

A. General Description of the Experimental Apparatus and Test Flow Loop

A system for automated measurement of differential and absolute pressure, temperature, and gas composition forms the basis for the acquisition and storage system of the experimental database. The measurements necessary and the systems used to make them are shown conceptually and schematically in figures 2 and 3. Included in the measurement and data storage system (fig. 3) is the provision for periodic calibration of the differential and absolute pressure transducers. The general philosophy used in the development of the measurement system provided by NBS was to tie each measured parameter to the national standards of measurement maintained by NBS (see fig. 2). Assessment of the magnitude of the effects of each parameter on the total measurement uncertainty for the orifice discharge coefficient was determined by a sensitivity analysis. This analysis was used to determine the rigor with which each measured parameter was compared with national standards.

B. Sensitivity Analysis of the Measurement System and Variation of the Discharge Coefficient with Various Parameters

The effect of variation in the parameters upon which the orifice meter discharge coefficient depends forms the basis for analysis of the sensitivity and uncertainty of the measurement system. This analysis is based on the mathematical expression relating the measured parameter values to the discharge coefficient. This expression, which is derived in Appendix C, is given by

$$C_d = \dot{m}(1 - \beta^4)^{1/2} \Big/ \left[N d^2 Y F_a \ (\rho \Delta P)^{1/2} \right], \qquad (1)$$

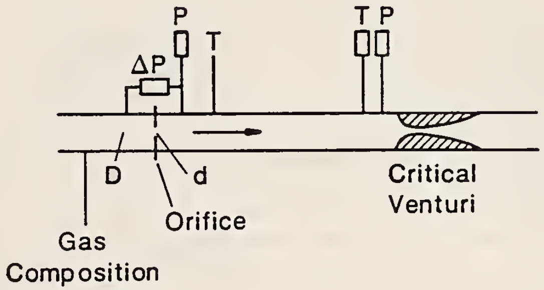
where C_d = orifice discharge coefficient,
$\dot{m}$ = mass flow rate through the orifice,
d = diameter of the orifice,
N = a constant whose value depends on the units of the measured parameters ($N = \pi/2\sqrt{2}$ for commensurate units),
ρ = density of the flowing fluid, natural gas in this project,
Y = adiabatic expansion factor,
F_a = orifice thermal expansion factor,
ΔP = the differential pressure developed across the orifice meter,
β = d/D, the beta ratio, and
D = the diameter of the meter tube.

FORMULATION

$$\dot{m} = F_a N C_d d^2 Y \sqrt{\frac{\rho \Delta P}{1 - \beta^4}}$$

$$C_d = f(Re)$$

$$Re = \frac{4\dot{m}}{\pi \mu D}$$



Symbol	Parameter or Function	Measurement Traceability
C_d	Orifice discharge coefficient	Calculated from formulation
d	Orifice diameter	Length standard
D	Pipe diameter	Length standard
F_a	Thermal expansion factor of the orifice	Calculated from formulation
$\dot{m}$	Mass flow rate	Mass & time standards via calibration
N	Units conversion constant	------------
P	Static pressure	Pressure standards
ΔP	Orifice differential pressure	Pressure standards
Re	Reynolds number	Calculated from formulation
T	Test fluid temperature	Temperature standards
Y	Adiabatic expansion factor	Eq. of state calculation
β	d/D, diameter	Length standards
μ	Test fluid viscosity	Corresponding states transport model
ρ	Test fluid density	P, T and gas composition Equation of state calculation

Figure 2. Orifice meter discharge coefficient measurement system and parameters

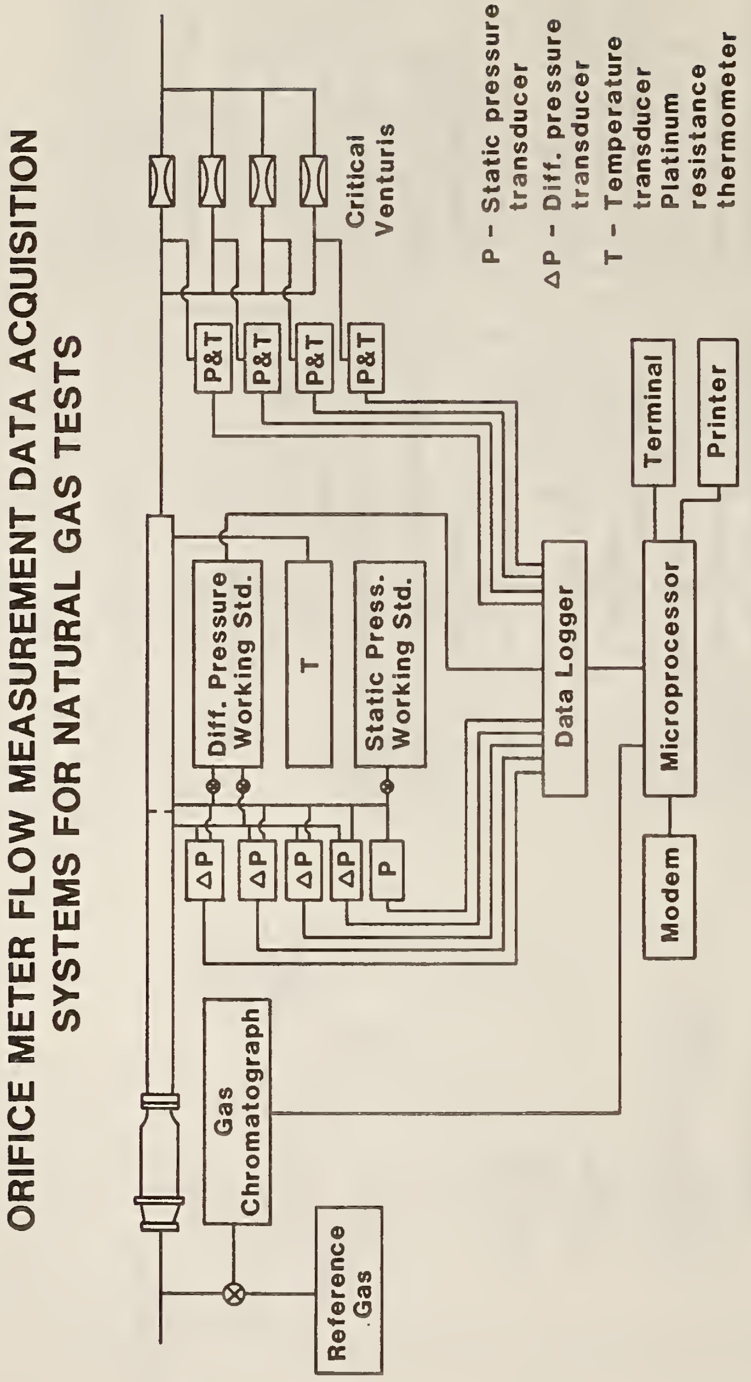

ORIFICE METER FLOW MEASUREMENT DATA ACQUISITION SYSTEMS FOR NATURAL GAS TESTS
Reference Gas
Gas Chromatograph
ΔP
ΔP
ΔP
ΔP
P
Diff. Pressure Working Std.
T
Static Press. Working Std.
P&T
P&T
P&T
P&T
Critical Venturis
Data Logger
Microprocessor
Modem
Terminal
Printer
P - Static pressure transducer
ΔP - Diff. pressure transducer
T - Temperature transducer Platinum resistance thermometer

Figure 3. Orifice meter flow measurement data acquisition systems.

Each of these parameters is either measured directly or is the result of observed values of two or more auxiliary parameters. The two diameter values are measured directly; the remaining parameters are derived from auxiliary observations, tabulated data, equations of state or models of transport properties. Several of the auxiliary measurements require calibration to make a direct tie to the U. S. national measurement system as maintained by NBS. Discussions of the methods of calibration and measurement traceability for each of these are given later in this section. Here we discuss the sensitivity of the discharge coefficient to variations in the parameters appearing explicitly in eq (1).

The effect on the discharge coefficient, C_d, of variations in a given parameter are obtained in the usual manner by differentiating C_d with respect to that parameter. The results were used to select the procedures and hardware for the data collection activities. The following list gives the expressions for the relevant partial derivatives and the corresponding expressions for the relative variation of the discharge coefficient, $\Delta C_d/C_d$, due to relative changes in each parameter.

Mass Flow Rate Variation

$$\frac{1}{C_d}\,\frac{\partial C_d}{\partial \dot{m}} = \frac{1}{\dot{m}}\,; \qquad \frac{\Delta C_d}{C_d} = \frac{\Delta \dot{m}}{\dot{m}}$$

The discharge coefficient varies linearly with the mass flow rate. As will be discussed later, the uncertainty in the mass flow rate was determined from calibration procedures used to determine the discharge coefficients for each nozzle of the set used as flow standards. The magnitude of this variation/uncertainty in the measurement of the nozzle discharge coefficients is taken as an upper limit target for the other independent parameter measurements.

Flowing Fluid Density Variation

$$\frac{1}{C_d}\,\frac{\partial C_d}{\partial \rho} = -\frac{1}{2\rho}\,; \qquad \frac{\Delta C_d}{C_d} = -\frac{1}{2}\,\frac{\Delta \rho}{\rho}\,.$$

The density of natural gas is a computed parameter in this work. Variation in its value depends on the accuracy of the equation of state used for the computation, and on the accuracy of the observed parameters which are the input data to the computation, i.e., pressure, temperature, and gas composition. The equation of state of Starling and coworkers [2] is used in this work. A comparison of the calculated and experimental values of pertinent parameters is given in Appendix D. Although the estimate of the accuracy of the calculated properties varies somewhat with pressure and temperature, differences between experimental and calculated values do not exceed 0.1% over the pressure and temperature region covered by the data. This level of accuracy represents the current state of the art and is a limiting component in the total error budget.

Orifice Expansion Factor Variation

The expansion factor, Y, depends on the ratio of the orifice differential pressure to the downstream static pressure (X), on the β ratio, and on the real-gas isentropic exponent (k). Values of X are computed from the pressure and differential pressure data, and values of k are computed using the equation of state described in section III. In practice, the values of Y range from 1.0002 to 1.0005.

The uncertainty in Y is dominated by the uncertainties in X and k. If one assumes that the uncertainties in X and k are 10%, one finds an uncertainty in Y of approximately 0.08%. Because the uncertainties in X and k are much less than 10%, we conclude that the uncertainty in Y is much less than 0.1%. The uncertainty in Y may be ignored under these circumstances and the contribution from this term dropped from the total uncertainty statement.

Orifice Thermal Expansion Factor Variation

The effect of variations in the orifice thermal expansion factor, F_a, is small due to the magnitude of the thermal expansion coefficient of the orifice plate material, stainless steel. The thermal expansion of stainless steel is of the order of 10^{-5}/°C, and for the temperatures used in this work (15 to 40°C), errors in the measured temperature and calculated expansion coefficient are extremely small.

Differential Pressure Variation

$$\frac{1}{C_d}\,\frac{\partial C_d}{\partial(\Delta P)} = -\,\frac{1}{2\Delta P}; \quad \frac{\Delta C_d}{C_d} = -\,\frac{1}{2}\,\frac{\Delta(\Delta P)}{(\Delta P)}\,.$$

The variation of the discharge coefficient with the differential pressure across the orifice meter is similar to that of the flowing fluid density. However, this measurement has traditionally been one of the more difficult to make with a small uncertainty. The approach taken in this work was to make a large number of differential pressure measurements using high quality, industrial-grade transducers, and to calibrate them frequently against appropriate working standards. In this way the uncertainty in this parameter is composed of a component describing the performance of each transducer and a component describing that of the working standard. The working standard was selected to minimize the uncertainty in differential pressure at the elevated static pressures at which these tests were run and to provide a practical means of performing the calibration while maintaining its accuracy. Two sets of differential pressure transducers were used: one to cover the differential pressure range up to approximately 40 inches of water (1.4 psid or approximately 10,000 pascals), and the other the range from 40 to 150 inches of water (5.4 psid or 38,000 pascals). This was done to reduce the uncertainty component in the transducer performance at the lower differential pressures.

The absolute uncertainty in the measurement of the differential pressure is nearly constant over the pressure range. Therefore, the relative uncertainty increases as the differential pressure decreases. As a result, the minimum pressure used was approximately 10 inches of water (0.4 psid or 2500 pascals). A realistic estimate of the uncertainty in the differential pressure working standard is approximately 3 parts in 10,000. Taking this as the uncertainty in the differential pressure value, one obtains approximate relative uncertainties for the highest and lowest nominal differential pressures used in the testing procedures of 0.03% (differential pressure of 150 inches of water) and 0.4% (differential pressure of 10 inches of water).

Orifice and Meter Tube Diameter Variations

$$\frac{1}{C_d}\frac{\partial C_d}{\partial d} = -\frac{2}{1-\beta^4}\frac{1}{d} \; ; \quad \frac{\Delta C_d}{C_d} = -\frac{2}{1-\beta^4}\frac{\Delta d}{d} \; .$$

$$\frac{1}{C_d}\frac{\partial C_d}{\partial d} = -\frac{2\beta^4}{1-\beta^4}\frac{1}{D} \; ; \quad \frac{\Delta C_d}{C_d} = -\frac{2\beta^4}{1-\beta^4}\frac{\Delta d}{D} \; .$$

The $2/(1-\beta^4)$ term in these relations amplifies the effects of uncertainty in the diameter measurements on that of the discharge coefficient. For the range of beta ratios used in this work the magnitude of this term ranges from 2 (for $\beta = 0.1$) to 3 (for $\beta = 0.75$).

All diameter measurements were estimated to be made with an absolute uncertainty of approximately 0.0002 inches (5 μm). The effects of this uncertainty on the relative uncertainty in the discharge coefficients are tabulated below for both the orifice and meter tube diameters. The small diameter meter tubes are the most seriously affected by the smaller beta ratio orifices.

Meter Tube Diameter (inches)	Orifice Diameter (inches)	Beta Ratio	$\left[\frac{\Delta C_d}{C_d}\right]_d$ (%)	$\left[\frac{\Delta C_d}{C_d}\right]_D$ (%)
6.0	0.63	0.11	6.3×10^{-2}	8.1×10^{-7}
6.0	1.25	0.21	3.2×10^{-2}	1.3×10^{-5}
6.0	3.00	0.50	1.4×10^{-2}	4.4×10^{-4}
6.0	4.00	0.67	1.2×10^{-2}	1.7×10^{-3}
10.0	1.0	0.10	4.0×10^{-2}	4.0×10^{-7}
10.0	3.0	0.30	1.3×10^{-2}	3.3×10^{-5}
10.0	5.0	0.50	8.5×10^{-3}	2.7×10^{-4}
10.0	7.5	0.75	7.8×10^{-3}	1.9×10^{-3}

C. Natural Gas Mass Flow Rate Measurement System and Uncertainty

1. General Description

The natural gas test loop at NGPL consisted of three major components: (1) a water bath heater, (2) the orifice meter test section, and (3) the critical nozzle manifold. The water bath heater had a capacity of one million BTU/hour to heat the gas entering the test loop. The purpose of the heater was to raise the temperature of the gas above the hydrocarbon dew point in the throats of the critical venturis. Otherwise there could be substantial errors in the calculated mass flow rate due to two-phase conditions in the nozzle throats. Estimates were made by Starling and coworkers [7] of the conditions in the nozzle throat for the onset of the two-phase region. These were related to the nozzle plenum conditions to provide operational information. The capacity of the heater was sufficient to raise the temperature of the gas to approximately 60 °F at the higher flow rates during the cooler part of the test schedule and to temperatures slightly in excess of 100 °F at the lower flow rates. Data collection procedures were confined to the summer and fall of each year so that the temperature of the gas could be maintained above 60 °F.

The configuration shown in figure 1 is that of the test loop as it existed in the 1984 tests. During the spring of 1985 a second nozzle manifold was added to allow most of the nozzles to be permanently installed. The second nozzle manifold carried the smaller of the nozzles and the larger, original manifold contained the largest nozzles. The nozzles were identified by their throat diameters.

Each leg of the nozzle manifolds contained a platinum resistance thermometer mounted in a thermometer well, a plenum pressure tap, and a flow straightener. The thermometer well was located upstream of the flow straightener with the pressure tap located 1 to 3 pipe diameters upstream of the nozzle inlet. Calculation of the mass flow rate of natural gas through the system was based on the values of these temperatures and pressures for each operational nozzle of the manifold.

2. Natural Gas Mass Flow Rate Calculation and Nozzle Discharge Coefficient Values

The mass flow rate of natural gas, $\dot{m}$ (lb/sec), through one of the critical nozzles is calculated using

$$\dot{m} = \frac{P\, A_t C^* \, C_d}{(RT)^{1/2}} , \tag{2}$$

where P = inlet static pressure (psia),
A_t = nozzle throat area, (in^2),
C^* = critical flow factor for the flowing fluid,
C_d = nozzle discharge coefficient,
R = gas constant (ft-lb$_f$/lb-°R), and
T = inlet gas temperature (°R).

All of the parameters in eq (2) except the discharge coefficient and critical flow factor are measured or computed from measured parameters or are thermodynamic constants. The discharge coefficient must be determined through calibration of the nozzle. The nozzles were calibrated in air flows at CEESI. A report of these tests [8] characterizes the dependence of the discharge coefficient upon the Reynolds number based on plenum viscosity and throat diameter. The Reynolds number value is computed using

$$R_d = \frac{48\dot{m}}{\pi d \mu} \qquad (3)$$

where $\dot{m}$ = mass flow rate (lb/sec),
d = nozzle throat diameter (inches), and
μ = natural gas absolute viscosity (lb/ft-sec).

Computation of the viscosity was based on the nozzle inlet conditions since no measurements were made in the throat.

Each of the nozzles was calibrated in air over the range of Reynolds numbers for which they were expected to be used in the natural gas tests. Since the nozzles were calibrated using a surrogate fluid having physical properties different from those of natural gas, the pressures at which the calibration data were taken were adjusted to encompass the anticipated range of Reynolds numbers for the natural gas tests.

To calculate the nozzle discharge coefficients during the natural gas tests, the following mathematical expression was used to characterize the discharge coefficient calibration data of each nozzle:

$$C_d = A + B\,R_d^{-1/2}. \qquad (4)$$

Values of the coefficients A and B were determined using the method of least squares and are given in table 2 with the residual standard deviations of the fits. The fitting procedures and the resulting estimates were performed by CEESI.

Table 2. Coefficients of the nozzle discharge coefficient model

Nozzle Designation	A	B	Residual Std. Dev.	Nozzle Holder (inches)
0.0950	0.99044	3.85	0.00033	2
0.1250	0.98270	8.29	0.00021	2
0.1880	0.99642	- 6.77	0.00032	2
0.2496	0.99347	- 6.666	0.00010	2
0.3750	0.99064	- 4.04	0.00024	2
0.5328	0.99940	- 9.77	0.00016	6
0.7537	0.99773	- 0.80	0.00025	6
1.0648	0.99352	10.36	0.00059	6
1.3751	0.98849	26.9	0.00041	6
1.9450	0.99547	- 9.9	0.00029	10
2.3300	0.99389	- 3.49	0.00044	10

The 0.1250 nozzle listed above was not part of the NGPL nozzle set. The original nozzle, for which discharge coefficients are reported in [8], exhibited unusual behavior in the calibration tests and was found subsequently to have a defect sufficiently large to warrant manufacture and testing of a second nozzle. This was done and the results of the calibration tests are given in Appendix F.

The critical flow factor, C^*, in eq (2) characterizes the real gas effects of the fluid passing through the nozzle. The calculations of Johnson [9] were used to obtain these values for the calibration fluid, which was air. The approach used to calculate C^* for the natural gas mixtures used at Joliet is discussed in Section III.

3. Uncertainty in the Nozzle Discharge Coefficient Value

The uncertainty in the value of the nozzle discharge coefficient calculated using eq (4) consists of the random variation in the discharge coefficient data upon which the coefficients A and B are based, and the contributions of the various measured or inferred parameters from which the discharge coefficients for a particular nozzle are calculated. The random variation may be estimated from the least squares procedure used to assign values to A and B via the residual standard deviation of the fit. Three standard deviations will be used to attain a 99% confidence level in this estimate.

Estimates of the contribution to the uncertainty from the independent variables on which C (nozzle) depends follow from a rearrangement of eq (2):

$$C_d = \frac{\dot{m}\sqrt{RT}}{PA_t C^*} . \qquad (5)$$

Mass Flow Rate - The uncertainty in the mass flow rate measurement depends upon which of the two CEESI flow measurement system was used in the nozzle calibration. The primary system is based on a tank of accurately known volume from which gas is expelled through the nozzle under test for a measured time period. The secondary system consists of nozzle sets calibrated in this way on the primary system. These are then used in parallel combinations as transfer standards for test nozzle calibration at flow rates substantially above the maximum of the primary system. Consequently, the uncertainty of the secondary calibration system is larger than that of the primary system since it must include both primary system uncertainty and reproducibility of nozzle calibration using it. CEESI estimates the uncertainty of the primary system at 0.1% of the mass flow rate value and the secondary system has an uncertainty of 0.25% of the mass flow rate value. Uncertainties for both mass flow rate determination systems will be considered to contribute systematic error in the calibration of nozzle discharge coefficients. Nozzles with diameters up to and including the 0.5328-inch nozzle were calibrated with both the primary and secondary systems and are assigned the smaller uncertainty value. The larger nozzle calibrations used only the secondary system.

Gas Constant - The uncertainty in the gas constant value is approximately 1 part in 30,000 or 0.003% [10]. This uncertainty is so much smaller than that of the mass flow rate and the other parameters that its effect is neglected in the analysis of error propagation.

Pressure - The relative uncertainty in the pressure value claimed by CEESI is 0.04%.

Temperature - The level of uncertainty in the temperature value is 0.1 °F (0.055 °C) and is taken to be random. This gives a relative uncertainty of 0.02%. (Temperature measurement is discussed fully in sec. II.E.)

Nozzle Throat Area - Uncertainty in the nozzle throat area, or diameter, does not contribute to the uncertainty in the nozzle discharge coefficient because the same diameter value is used during calibration and subsequent use of the nozzle. As described later, however, there is an additional uncertainty in the measured mass flow rate through a single nozzle when the temperature during test runs significantly differs from that at the time of calibration. This additional term is added systematically to the error budget for the mass flow rate. It does not appear in this error budget for the nozzle discharge coefficient, but is discussed in a subsequent section related to total uncertainty of these measurements.

Critical Flow Factor for Air - The calibration of the nozzles at CEESI used air as the flowing fluid. The uncertainty in the critical flow factor for air will be estimated from comments made by Johnson [8] concerning the level of agreement between his calculation of physical parameters for air and tabulated thermodynamic properties (Hilsenrath [11]) for air.

The critical flow factor is defined by the following equation:

$$C^* = G_t \ (RT_p)^{1/2}/P_p \qquad \text{and}$$

$$G_t = p_t U_t \, ,$$

where G_t = mass flow rate per unit area,
T_p = plenum temperature,
P_p = plenum pressure,
p_t = density in the nozzle throat, and
U_t = velocity in the nozzle throat.

Johnson calculated the gas density using an equation of state to compute its compressibility, and then computed the density with the compressibility to carry the real gas effects. His stated level of agreement for compressibility values with reference [11] is 0.1 percent as a worst case estimate.

Johnson's calculation of gas velocity in the throat was dependent upon values of the enthalpy obtained from tabulated values in [11]. It is assumed that the interpolation methods used by Johnson did not significantly increase uncertainty in the enthalpy values used for velocity computation. Therefore, the enthalpy uncertainty stated in [11] of approximately 1 or 2 x 10^{-4} is the primary uncertainty contribution to the computed throat velocity and is considerably below that of the compressibility. The uncertainty in C^* is the sum of the uncertainties in throat velocity and density, or 0.12%.

The total error budget for the mass flow rate through a single nozzle, to be developed in subsequent sections of this report, includes the uncertainty in the nozzle discharge coefficient and the uncertainty in C^* for natural gas. For natural gas we develop numerical estimates of the uncertainty in C^* using the equation of state. Thus, the total uncertainty in the mass flow rate includes the uncertainty in C^* for air (from the nozzle calibrations), estimated at 0.12%, and the uncertainty in C^* for natural gas (from the test runs), estimated numerically.

Combined Uncertainty in Nozzle Discharge Coefficients

Calculation of the total relative uncertainty in percent in the discharge coefficient for each nozzle requires that the random uncertainty from the fit used to determine A and B be combined with the random and systematic uncertainties in the values of C_d calculated from eq (5). The uncertainties in the fit and in the values of C_d are combined additively but in the calculation of the latter the random contributions are combined in quadrature and the systematic components additively. Denoting the resultant total uncertainty by s_{C_d}, one has

$$s_{C_d}\ (\text{nozzle}) = \left[\left(3s_{C_d f}\right)^2 + (3s_p)^2 + 1/4\ (s_T)^2\right]^{1/2} + s_{C^*} + s_{\dot{m}}$$

where $s_{C_d f}$ = residual standard deviation of the fit for C_d, divided by C_d, expressed in percent,

s_p = the relative uncertainty in the nozzle pressure value in percent,

$s_{\dot{m}}$ = the relative uncertainty in the nozzle mass flow rate value in percent,

s_T = the relative uncertainty in the temperature in percent,

s_{C^*} = the relative uncertainty in the critical flow factor for air in percent.

For nozzles that were calibrated using CEESI's primary and secondary flow rate calibration systems, the total relative uncertainty in the discharge coefficient is based upon the primary system:

$$s_{C_d}\text{ (nozzle)} = \left[\left(3s_{C_d f}\right)^2 + (0.04)^2 + 1/4(0.02)^2\right]^{1/2} + 0.1 + 0.12$$

$$= \left[\left(3s_{C_d f}\right)^2 + 17 \times 10^{-4}\right]^{1/2} + 0.22.$$

For nozzles that were calibrated using CEESI's secondary system only, the total relative uncertainty in the discharge coefficient is computed using

$$s_{C_d}\text{ (nozzle)} = \left[\left(3s_{C_d f}\right)^2 + (0.04)^2 + 1/4(0.02)^2\right]^{1/2} + 0.25 + 0.12$$

$$= \left[\left(3s_{C_d f}\right)^2 + 17 \times 10^{-4}\right]^{1/2} + 0.37.$$

The six smallest nozzles, i.e., those having throat diameters of 0.5328 inches and smaller, were calibrated using the CEESI primary flow rate measurement system. The remainder used the secondary system only and are assigned the larger relative uncertainty.

The uncertainty in the mass flow rate of natural gas through a single critical nozzle depends on the uncertainties in the nozzle discharge coefficients determined at CEESI. A conservative estimate of this uncertainty is obtained in Section IV by treating $s_{C_d f}$ as a random uncertainty and the remaining contributions as a systematic uncertainty.

D. Static and Differential Pressure Measurement Systems and Standards

1. Pressure Measurement Requirements and Units

Measurement of the static and differential pressures at each orifice meter and nozzle was one of the primary measurements made during this project. The criteria used in selecting the measurement methods were:

- The method must significantly reduce or eliminate the need for manual transcription of data, and therefore, the error rate associated with it, and be compatible with the automated data acquisition and storage techniques used in the project.

- The method must incorporate working standards of pressure for in-situ calibration of static and differential pressure measurement devices.

- The method must be capable of an accuracy consistent with the level of uncertainty in the measurement of the mass flow rate. This is determined by the uncertainty in the calibration of the critical nozzles.

- The capability to maintain this accuracy level between successive pressure calibrations must be retained.

Throughout this report several sets of pressure units are used. It is common industrial practice in the United States to use inches of water in describing differential pressure measurement and pounds per square inch for absolute, gauge, or differential pressures. The abbreviations psia, psig, and psid will be used for these, respectively. To satisfy a broader community, the SI system (pressure units of pascals) is generally included parenthetically. For convenience in the remainder of this document the following conversion constants between the pressure units are given. These are generally recognized and are contained in American National Standard Z210.1-1976.

1 pascal = 1 newton/meter^2
1 pound force/inch^2 = 6894.76 pascals
1 inch of water (60 °F, 15.55 °C) = 249.08 pascals
1 inch of water (39.2 °F, 4 °C) = 248.84 pascals

2. Differential Pressure Transducers

Measurements of the differential pressure across the orifice meter were made using industrial quality, diaphragm type, differential pressure transducers. Voltage output from all transducers were measured using a data logger having a 5 1/2-digit resolution, i.e., 1 part in 200,000. This resolution is much below any other source of error and is neglected in the uncertainty analysis. The pressure transduction instruments were selected by the API orifice database project committee and were compatible with the electronic data acquisition and storage system used in the project. Several sets of these transducers were used during the course of the project. The basis for transducers changes is discussed later in this section. Provision for frequent calibration of these devices was designed into the data acquisition system to provide the capability to attain sufficiently accurate characterization of the transducer response and maintain traceability with the U.S. national measurement system.

Two operating ranges were selected to cover the range of orifice meter flow rates. The maximum flow rates corresponded to differential pressures of 150 to 250 inches of water (5.5 to 9.2 psid, 37 to 63 kilopascals). To achieve redundancy in the measurement system, two transducers for each of the two ranges were used. The low range differential pressure transducers had a span of approximately 40 inches of water. Three sets of high range transducers were used. The first two sets were used in the test data collected in 1984; one had a range of 200 inches of water and the other 150 inches of water. During 1985 a third set of both high and low range transducers was used. In that case the largest differential pressures measured were approximately 250 inches of water. The upper end of the lower range was maintained near 40 inches of water.

Figure 4 shows the interconnection of the differential pressure transducers, the orifice meter, and the differential pressure calibration apparatus. The latter is discussed in more detail below. It should be noted that the connections of the differential pressure transducers to the orifice meter taps were made on the top set of tap holes only. These were located at the 12 o'clock position. The connection location shown in figure 4 facilitates the presentation but does not reflect the actual connection configuration. Each of the transducers was isolated from the remainder of the transducer manifold with seven-valve manifolds which allowed any of the transducers to be connected to the atmosphere, the pressure developed in the orifice meter, or the pressure developed in the calibration portion of the transducer manifold. In normal operation the full range of differential pressures was admitted to each transducer, both for pressure measurements during test runs and for calibration procedures. Each transducer was fitted with a mechanical stop to arrest the motion of its diaphragm before damage occurred.

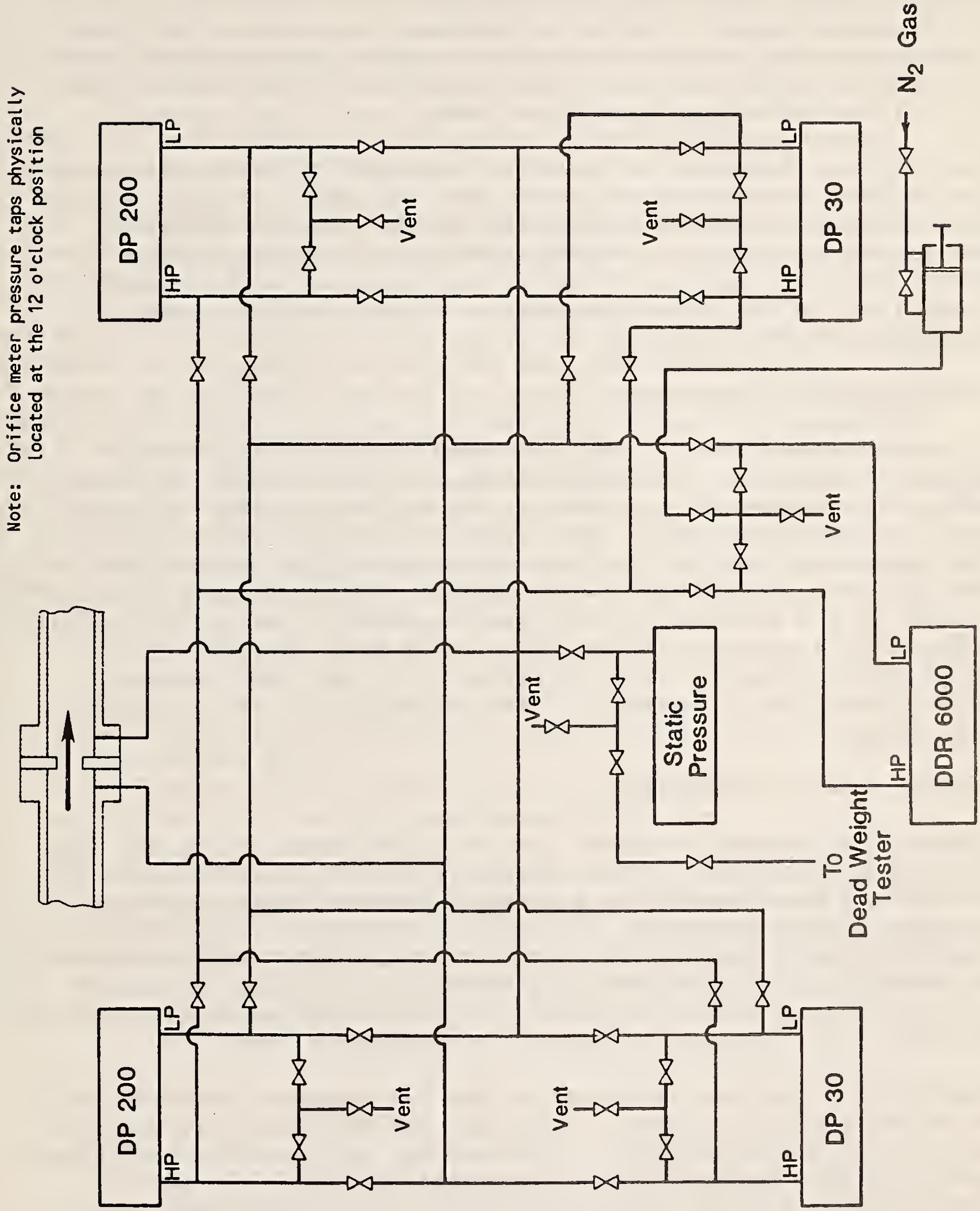
The 40-inch transducers had their operating span set to 40 inches of water for use in the lower differential pressure region. The original intent was to limit the low range transducers to 20 inches of water, but the transducers operated sufficiently well up to 40 inches that the low range was extended to 40 inches of water or below. The first set of transducers designated as 200 inches were actually transducers whose upper limit was 750 inches of water and had been re-spanned to 200 inches of water. These transducers were used until late August of the 1984 operating season. Because of a consistent difference between the upper range transducers and the lower range transducers in the region of response overlap, a series of operational tests of the transducers was performed. These tests are described fully in Appendix B and demonstrated that the procedures used immediately after the calibration of the transducers induced significant shifts of the zero differential pressure response in the high range transducers only. The procedures inducing this effect were those necessary to switch the transducer connections from the calibration side of the manifold to that of orifice meter.

Prior to August, 1984, calibration procedures were performed at a static or base pressure of 600 psig. Following the calibration, the transducers were valved onto the orifice meter side of the manifold which was operating in the pressure range 480 to 750 psig. In switching the valves between the two sides of the manifold, differential pressure excursions much larger than the range of the transducers were presented to the transducers. These excursions caused changes in the zero differential pressure response of approximately 0.5 inches of water in the high range transducers only. This appeared to be a constant shift in the response until the transducers were overpressured again. During the course of these diagnostic tests the low range transducers were connected to the manifold in the same way as the high range transducers and were subjected to the same overpressurization regimes. The maximum shift in the zero differential response appeared to be less than 0.03 inches of water for one and 0.01 for the other of these transducers.

Because of this difficulty, the high range transducers and one of the low range transducers were replaced. The high range transducers were replaced with transducers having a maximum span of approximately 175 inches of water. The replacement of the low range transducer was not required, but was done anyway. The performance of the second set of high range transducers was improved over the initial set, although the upper flow rates at which orifice meters could be tested was reduced by approximately 25%. As a result of these circumstances, the orifice meter test points were rerun. In the results database of this project, test points above 40 inches of water are excluded because of the poor performance of the high range transducers during this period. However, the points below 40 inches of water remain as part of the database since these transducers were found to be operating in an acceptable manner.

In addition to the change of transducers, a change in calibration procedures was made. Rather than calibrate the differential pressure transducers at 600 psig, the base pressure was adjusted to be reasonably close to that of the test loop at the time of calibration. This pressure value was obtained from the Joliet station operations personnel shortly before the calibration procedures began.

Before the 1985 operating season was begun, a new set of high and low range transducers were obtained and mounted. These were used throughout the 1985 testing schedule and performed well.



Note: Orifice meter pressure taps physically located at the 12 o'clock position

DP 200
LP
HP
Vent
DP 30
LP
HP
Vent
N_2 Gas
Vent
Static Pressure
Vent
DDR 6000
LP
HP
To Dead Weight Tester
DP 200
LP
HP
Vent
Vent
DP 30
LP
HP

Figure 4. Differential pressure transducer manifold schematic diagram.

Calibration of the transducers was performed over the full operating pressure range using the small pressurization pump shown at the lower right in figure 4. These procedures were performed with nitrogen as the calibration fluid. The working pressure standard for differential pressure was a Model DDR-6000 quartz bourdon tube differential pressure transducer manufactured by the Ruska Instrument Corporation [12]. This was connected to the transducer manifold through a three valve manifold. The DDR 6000 was filled only with nitrogen and never with natural gas since it was not of an explosion proof design.

This was done to eliminate the hazard of explosion in the control room area of the instrumentation shed where it was located. Purging of the manifold with nitrogen was done with the appropriate venting valves located on each transducer. The differential and static pressure transducer manifolds were maintained at the operating base pressure levels when not in use to minimize adverse effects due to pressurization/depressurization cycling.

3. Static Pressure Transducers

Static pressure measurements were made using industrial grade, diaphragm-type transducers. Pressure measurements are required at several locations in the measurement system, i.e., the orifice meter and each critical flow nozzle's plenum. Five static pressure transducers were used for these measurements. An additional set of four transducers, of somewhat lesser quality, were used to measure the downstream pressure of each nozzle in the main manifold to give a measure of whether the nozzle had achieved conditions necessary for critical flow. Details of the interconnecting piping for both the differential and static pressure transducers are given in Appendix A with photographs of the transducer mounting hardware.

4. Working Pressure Standards

Incorporation of working standards into the measurement system was done using two types of devices. The working pressure standard for the static pressure measurements was a model HK-1000 ball-type deadweight pressure gauge manufactured by Ametek [12]. This device was used to develop known pressures from 400 to 800 psig which were applied to the static pressure transducers during calibration procedures. In all of the calibration procedures the working fluid was nitrogen obtained from bottles kept in the transducer room of the instrument shed.

The deadweight tester was calibrated by the NBS Pressure Standards Group before it was placed in service. The Ruska DDR-6000 was calibrated by the manufacturer before delivery to NBS and was calibrated several times against a high pressure mercury manometer [13] at the NBS Boulder Laboratories before it was placed in service at the Joliet test site. It was calibrated again by the NBS Pressure Standards Group after the testing program was completed.

5. Static Pressure Working Standard

The calibration of the deadweight tester produced an effective area for the ball and an uncertainty in this value over the calibration pressure range of 60 to 550 psia. A small pressure dependence of the ball area was indicated by the presence of a small apparent residual force in addition to that generated by the weight stack itself. Adjustment for this effect is afforded by assignment of a non-zero value as the tare force of the deadweight tester. Mass values were assigned to the weights, the ball, and the weight carrier of the deadweight tester. These values and the area of the ball, the local acceleration of gravity, the tare force, and the atmospheric parameters (barometric pressure, relative humidity, and air temperature) were used to compute the pressure developed by the deadweight tester during static pressure transducer calibration.

Computation of the pressure developed by the deadweight tester involved computation of the density of air, the assigned area of the ball, the tare force, and the total mass of the weight stack. Since pressure is defined as force per unit area, the force exerted on the deadweight tester's ball must be calculated for each stack of weights used in developing a particular pressure. The apparent mass value of the weight stack is computed using eq (6), which accounts for the buoyant force of the atmosphere on the objects exerting a force on the ball. The apparent mass is the difference between the force of gravity pulling the weight stack toward the center of the earth and the buoyant force of the atmosphere directed in the opposite direction.

$$M_a = M_t (1 - \rho_a/d_w), \tag{6}$$

where M_t = true mass of the combined weight stack,
M_a = apparent mass,
d_w = density of the weight material, and
ρ_a = density of the air surrounding the weight.

The weights were made of stainless steel having an assigned density of 7.8 g/cm^3. However, the materials making up the weight stack and contributing to the force on the ball were not only the stainless steel weights, but also the weight carrier and the ball itself. The true mass values, weight designations and nominal pressure produced by each weight, when placed on the deadweight tester, are given in table 3.

Table 3. Pressure gauge weight mass values, maker number 76837

Nominal Pressure	Weight Designation	True Mass Value (lbm)
90 psi	# 1	3.974990
100 psi	# 2	4.416426
" "	# 3	4.416539
" "	# 4	4.416564
" "	# 5	4.416808
" "	# 6	4.416791
" "	# 7	4.417021
" "	# 8	4.416643
" "	# 9	4.416521
50 psi	# 10	2.208379
20 psi	# 11	0.883407
20 psi	# 12	0.883368
10 psi	# 13	0.441675
5 psi	# 14	0.220829
2 psi	# 15	0.088337
2 psi	# 16	0.088335
1 psi	# 17	0.044160
Weight carrier		0.440740
Ceramic ball		0.000966

(assumed density of stainless steel is 7.8 g/cm^3)

Once the apparent mass of the weight stack had been computed the pressure value was computed using

$$P = (M_a g - W) / A_b[1 - a(T - 23)], \qquad (7)$$

where P = pressure,
g = local acceleration of gravity calculated for the Joliet test site (980.2429 cm/sec^2) [14],
W = tare force determined in calibration of the instrument,
A_b = area of the ball,
a = area thermal expansion coefficient for the ceramic ball/stainless nozzle combination, and
T = temperature in degrees Celsius.

Equation (7) includes a correction for the small thermal expansion of the stainless steel/ceramic ball combination. The reference temperature of 23 °C is that at which the testers were calibrated. Introduction of the appropriate units for each of the quantities in eq (7) results in eq (8), which was used to compute the pressure developed by the deadweight tester. Equation (8) gives the pressure in the SI units of pascals (newtons/meter^2). The conversion factor 1.450377×10^{-4} psi/pascal is used to express the pressure value in customary units of psi.

$$P = \frac{[0.4535924\ (\mathrm{kg/lb}) \times M_a\ (\mathrm{lb}) \times 9.802429\ (\mathrm{m/sec^2})] - W}{A_b\ (\mathrm{m^2})\ \{1 + 0.0000167\ [T(^\circ\mathrm{C}) - 23]\}} \quad . \qquad (8)$$

6. Uncertainty in the Static Pressure Working Standard

The statement of uncertainty in one of the working pressure standards is composed of the following components:

- the uncertainty in the area assigned to the ball,
- the uncertainty in the buoyancy correction for the weight stack,
- the uncertainty in the mass value of the weight stack,
- the uncertainty in the tare force,
- the uncertainty in the value of the acceleration of gravity, and
- the uncertainty in the values of the thermal expansion coefficients for the ceramic ball and the stainless steel nozzle/ball retainer.

The uncertainty in the area assigned to the ball and that assigned to the tare force are obtained from calibration of the deadweight tester against the national working pressure standard by the NBS Pressure & Temperature Division (Calibration Report P-7959). The effective area assigned to the ball was 2.850007×10^{-5} m^2 with a relative random uncertainty of 22.9 parts per million. The tare force value assigned was 6.779506×10^{-3} newtons with an uncertainty of 1.8315×10^{-3} newtons. The relative systematic uncertainty in the national pressure standard used to assign these values is reflected in the uncertainty in the effective area value and is 54 parts per million of the effective area.

The uncertainty in the buoyancy correction for the weight stack is due to the effects of uncertainty in the density of the air and the weights. The relative uncertainty in the density of the weights is taken to be 1%. As is the relative uncertainty in the density of air. A discussion of the effect of uncertainty in computed air density values on deadweight testers is given in reference [1]. Computation of air density values used the formulation of Jones [10]. Taking partial derivatives of eq (7) and approximating factors of $M_a g/(M_a g-W)$ by unity, one obtains

$$\frac{1}{P}\,\frac{\partial P}{\partial \rho_a} = \frac{-1}{d_w - \rho_a}; \quad \frac{\Delta P}{P} = \frac{-\rho_a}{d_w - \rho_a}\,\frac{\Delta \rho_a}{\rho_a}\ , \text{ and}$$

$$\frac{1}{P}\,\frac{\partial P}{\partial d_w} = \frac{\rho a}{d_w - \rho_a}\,\frac{1}{d_w}\ ; \quad \frac{\Delta P}{P} = \frac{\rho_a}{d_w - \rho_a}\,\frac{\Delta dw}{d_w}\ .$$

These expressions give the relative uncertainties in the pressure due to the uncertainty in the buoyancy correction in eq (7). Substitution of nominal values for the density of air (0.00117 g/cm^3) and stainless steel (7.8 g/cm^3) gives values for the relative magnitudes of these effects of approximately 2 parts per million each. The combined effect is 4 ppm for relative uncertainty due to air buoyancy effects. This uncertainty component is taken to be random in effect.

The uncertainty in the assignment of the mass values for the stainless steel weights and the weight carrier is 15 micropounds at the 99% confidence level. The uncertainty in the mass assigned to the ball is less than 1 micropound. The total relative uncertainty in the mass of the weight stack combinations used in calibration procedures between pressures of 400 to 800 psia is 3 to 4 parts per million and is taken to be systematic.

The tare force assigned was 6.779506 x 10^{-3} newtons with an uncertainty of 1.8315 x 10^{-3} newtons. The relative uncertainty in this quantity is normalized by the total force exerted on the effective area of the ball/nozzle combination. For the pressure range 450 to 750 psia, the force ranges from approximately 88 to 147 newtons. Therefore, the relative uncertainty in the tare force ranges from 12 to 21 parts per million. The tare force uncertainty is taken as a random contribution in the pressure uncertainty since it is derived from the fitting procedures used in its determination.

The uncertainty in the local acceleration of gravity at the Joliet, IL County Court House is estimated [14] to be 0.002 cm/sec^2 relative to a value of 980.2429 cm/sec^2. We arbitrarily double the magnitude of this uncertainty estimate to account for changes in longitude, latitude and elevation of the test site relative to the court house. The relative uncertainty is therefore assigned to be 4 parts per million and is taken to be systematic.

The effects of uncertainty in the thermal expansion coefficients of the steel nozzle holding the ball and of the ball itself are estimated to be approximately 10% of the value of each [15]. Since operation of the deadweight testers was in the 20 to 25 °C range due to air conditioning of the transducer room, the magnitude of this effect on the uncertainty in the pressure is 3 to 5 parts per million [see eq (8)]. This contribution is taken to be systematic.

A statement of the total relative uncertainty in the deadweight tester pressure is obtained by combining the random contributions in quadrature and the systematic contributions additively. A summary of the various contributions is given in table 4. For those contributions which are dependent on the pressure range, the component of largest magnitude is used in the summation of error components.

Table 4. Relative uncertainty in the static pressure working standard

	Random (ppm)	Systematic (ppm)
Ball area assignment	23	54
Tare force	12 - 21	
Buoyancy correction	4	
Weight stack mass values		4
Acceleration of gravity		4
Ball/Nozzle thermal expansion coeff.		5
Component Summations	26 - 31	67

Total Estimated Uncertainty -- 93 - 98 parts per million

The total estimated relative uncertainty in the pressure developed by the deadweight tester for calibration of the static pressure transducers is taken to be 98 parts per million. The total estimated absolute uncertainty ranges from 0.045 at 450 psia to 0.074 at 750 psia.

7. Barometric Pressure Measurement and Its Uncertainty

The static pressure transducers were referenced to atmospheric pressure and calibrated in that manner. Computation of absolute pressure values for the nozzles and the orifice meter requires a measured value of the barometric pressure be added to the values obtained from the static pressure transducers. A mercury barometer was used at the Joliet station for this purpose. Its location, physically outside the test loop, required the use of a transfer device for measurement of the barometric pressure for the test runs. The mercury barometer was used to determine any offset in reading of the aneroid barometer used as the transfer device. Therefore, the uncertainty in the barometric pressure is the sum of that of the mercury and aneroid barometers. The uncertainty in the mercury barometer is taken to be 0.5 millimeters of mercury and is composed primarily of operator reading variability. The aneroid barometer was a small device which had a readability of 0.05 inches of mercury (1.3 millimeters of mercury). The combined uncertainty of these is 1.8 millimeters of mercury or 0.034 psia.

8. Uncertainty in the Differential Pressure Working Standard

The uncertainty in the differential pressure working standard is derived from its calibration. As mentioned earlier, several of these have been performed over the lifetime of this project. The initial calibrations were done at the NBS Boulder Laboratories using several types of instruments as the standard for the DDR-6000 used at Joliet. These were

- a piston gauge for setting elevated base pressures and for calibrating at an atmospheric base pressure,
- a high pressure mercury manometer [13], and

- a second DDR-6000 owned by NBS which had been calibrated previously using the dual float piston gauge method and the high pressure manometer.

Several base pressures were used in the calibration measurements. These included atmospheric pressure, 500 psia, and 600 psia. A piston gauge was used for calibration of the DDR-6000 at atmospheric pressure. The differential pressures ranged from 10 to 200 inches of water (2500 to 50,000 pascals) which was approximately one half the range of the instrument. The calibration procedures performed at NBS Boulder generally consisted of 16 or more differential pressure points at a fixed base pressure. Table 5 lists the results of these calibration measurements on the DDR-6000 s/n 32723.

Table 5. Calibration results for the differential pressure working standard

Date	Base Pressure (psig)	Calibrating Instrument	DDR-6000 Slope (psid/volt)	Residual Standard Deviation (pa)	(psid)	(in. H_2O)
Jan. 1984*	600	DDR-6000 (NBS)	1.45035	5.2	0.00076	0.021
Jan. 1985*	14	Piston Gauge	1.45013	0.7	0.00001	0.003
Jan. 1985*	500	Manometer	1.45016	9.9	0.00144	0.040
Jan. 1985*	600	Manometer	1.44997	6.2	0.00090	0.025
June 1986!	600	Dual Pist. Gauge	1.45038	5.0	0.00073	0.020

* - Calibration performed at the NBS Boulder Laboratories
! - Calibration performed by the NBS Pressure Standards Group, Calibration Report P-8053

The atmospheric pressure calibration of the instrument shows that its slope is linear to approximately 30 parts per million at the 99% confidence level (three standard deviations). This method of calibration is one that minimizes the uncertainty in the standards used in the calibration since only the uncertainty associated with the piston gauge itself applies. This piston gauge was calibrated against those used as U.S. national standards and has an uncertainty of 54 parts per million. This 54 parts per million is mostly systematic with a small random component of 4 to 5 parts per million. This random component contributes variability to the calibration of the DDR-6000 and is only a small part of the 30 parts per million seen in the variation of its slope. The remainder of the variability must be attributed to the inherent variability of the instrument.

The calibrations of the differential pressure working standard performed at the NBS Boulder Laboratories were done using instruments other than national standards to give an indication of the stability of the instrument over the period of the project. The value for the slope used for computation of the differential pressures developed during calibration of the transducers is that obtained by the NBS Pressure Standards Group. This group used the dual float piston gauge method and had the direct involvement of instruments used as U.S. national standards. The uncertainty in the assignment of the slope to the DDR-6000 is composed of the uncertainty of the standards used in the calibration and the variability of the instrument during the calibrations. The assignment of the slope was the result of a least squares fit to 30 calibration points taken over a time of several days. Three standard deviations of the slope value is 0.00012 psid/volt or 0.008% in relative terms. This variability added to the 100 parts per million (0.01%) uncertainty in the standards gives a total uncertainty in the DDR-6000 of 0.018% of the differential pressure value. Application of this relative uncertainty to the pressure values used during calibration of the transducers gives the following absolute uncertainties:

Calibrating Diff. Pressure		Uncertainty	
(inches of water)	(psi)	(inches of water)	(psi)
20	0.722	0.0036	0.0001
35	1.263	0.0063	0.0002
150	5.414	0.027	0.0010
250	9.023	0.045	0.0016

9. Pressure Transducer Calibration Procedures

The static and differential pressure transducers were calibrated in separate procedures using their respective working pressure standards. The order of the calibrating procedures was (1) low range differential pressure transducers, (2) high range differential pressure transducers, and (3) static pressure transducers. These procedures were performed before each day's data collection procedures and formed an integral portion of the database structures for the project.

a. Differential Pressure Transducer Calibration Procedures

Calibration of the differential pressure transducers begins by opening the valves connecting the transducers to the calibration gas manifold and isolating them from the natural gas plumbing. The calibration gas manifold includes a high-pressure, hand-operated pump, the differential pressure transducers and the differential pressure working standard. The calibration manifold is filled with nitrogen from a regulated source to a pressure of either 600 psig or to a value closely approximating that of the pipeline operating pressure as determined from the pipeline operating conditions of the Joliet station. Differential pressures are obtained by use of the hand pump to compress the gas in the high pressure side of the manifold. The low and high range transducers were calibrated using separate pressurization schedules.

The pressurization schedules were changed over the course of the testing program to accommodate changes in transducers and transducer ranges (see sec. II.D.13 for specific dates). The number of calibration points in the schedules was changed somewhat but not substantially. Either 9 or 10 point calibration schedules were used for the low range transducers with 11, 12 or 13 point schedules used for the high range transducers. The upper limits of the schedules were also adjusted to fit the various transducer ranges and the upper flow rate ranges desired for each orifice meter. At the beginning of the project the low range transducers were used only below approximately 20 to 25 inches of water and were calibrated through a 30 inch of water range. The calibration schedule was changed later in the 1984 season to 35 to 40 inches of water allowing the upper limit of measurement to be near 35 inches of water. All of the low range transducers were out-of-range above 41 to 42 inches of water. At that point the transducer's diaphragm was restrained by a stop. Table 6 gives a listing of the low and high range transducer schedules. This table was taken from the information displayed for the operator by the data acquisition system. The target voltages for the DDR-6000 were displayed for each calibration point along with the nominal pressure value.

Table 6. Differential pressure transducer calibration schedules

--------- Low Range --------		--------- High Range ---------	
Target Voltage	Nominal Pressure Level	Target Voltage	Nominal Pressure Level
0.00	0 inches of water	0.00	0 inches of water
0.30	12 " " "	0.50	20 " " "
0.50	20 " " "	1.00	40 " " "
0.70	28 " " "	1.49	60 " " "
0.90	36 " " "	2.24	90 " " "
0.80	32 " " "	2.98	120 " " "
0.60	24 " " "	4.23	170 " " "
0.40	16 " " "	5.97	240 " " "
0.20	8 " " "	4.98	200 " " "
0.00	0 " " "	3.73	150 " " "
		2.49	100 " " "
		1.24	50 " " "
		0.75	30 " " "
		0.00	0 " " "

Calibration observations of either set of differential pressure transducers began with an observation of the zero differential pressure of the DDR-6000. This was done with its crossover valves open. Several observations of this voltage were made and the mean value stored. The first nonzero differential pressure observation point of the schedule was then set by the NGPL operator using the hand pump to set the DDR-6000 voltage to a value within a few percent of the target value. When the DDR-6000 voltage had stabilized, five successive readings of the transducer voltages and of the DDR-6000 voltage were made, the means calculated, and the values stored by the data acquisition system. The last observation of either schedule was of the zero differential pressure response voltages. These were observed with the high and low sides of each transducer connected together through the crossover valves fitted to each transducer manifold. Following this observation the crossover valves were closed and the transducers were switched over to the natural gas portion of the manifold for orifice meter measurement procedures. A typical set of observations for both sets of differential pressure transducers is shown in table 7. The differential pressure of the calibration manifold as measured by the DDR-6000 working pressure standard is given in units of psid and nominally in inches of water. The transducer voltage values listed are the mean values.

Table 7. Differential pressure transducer calibration data for August 9, 1985 at a static pressure of 580 psig

Low range transducer calibration data

Obs. No.	Time	DDR-6000 Pressure (psid)	DDR-6000 Pressure (In. H20)	HW-003 Voltage (Volts)	HW-004 Voltage (Volts)
1	06:57:59	0.4381	12.140	4.41022	4.43062
2	06:59:26	0.7390	20.476	6.07872	6.09578
3	07:00:42	1.0307	28.558	7.68574	7.71160
4	07:01:45	1.3313	36.887	9.35030	9.37590
5	07:02:38	1.1876	32.906	8.55844	8.58190
6	07:03:45	0.8966	24.842	6.94800	6.97044
7	07:05:03	0.6028	16.703	5.32308	5.34382
8	07:06:15	0.3175	8.797	3.74336	3.76008
9	07:07:51	-0.0012	-0.033	1.98302	1.99596

High range transducer calibration data

Obs. No.	Time	DDR-6000 Pressure (psid)	DDR-6000 Pressure (In. H20)	HW-001 Voltage (Volts)	HW-002 Voltage (Volts)
1	07:10:45	0.7373	20.429	2.65206	2.65132
2	07:12:01	1.4598	40.448	3.29476	3.29414
3	07:12:41	2.1640	59.958	3.92008	3.91862
4	07:13:42	3.2775	90.809	4.90342	4.90496
5	07:14:28	4.3324	120.039	5.84006	5.84122
6	07:15:09	6.1320	169.900	7.43586	7.43792
7	07:15:58	8.6536	239.764	9.67372	9.66958
8	07:17:20	7.2130	199.851	8.38762	8.39286
9	07:18:33	5.3951	149.481	6.77700	6.78084
10	07:19:23	3.6864	102.138	5.26128	5.26234
11	07:20:12	1.8199	50.424	3.60878	3.61062
12	07:20:44	1.1257	31.190	2.99200	2.99500
13	07:22:02	0.0004	0.010	1.99990	1.99734

b. Static Pressure Transducer Calibration Procedures

Calibration of the static pressure transducers was done over a pressure range that exceeded the test loop operating pressure range. Initially the calibration range was 400 to 700 psig; however, as the data collection phase of the project progressed, test loop operating pressures exceeded 700 psig. To harmonize the operation and calibration pressure ranges of the transducers, another point was added to the calibration schedule at 800 psig. Daily calibration procedures were performed on the five static pressure transducers used to measure the orifice static pressure and the four nozzle plenum pressures. The four transducers used to measure the downstream static pressure were calibrated shortly before their installation but not again. This was done because these measurements were non-critical for data reduction purposes. Although the pressure ratio across the critical venturis was an operational surveillance measurement. It was not sensitive to errors in the downstream pressure of a few percent.

The calibration schedule consisted of a sequence of pressures developed by the deadweight tester and applied to the five static pressure transducers beginning at 400 psig. The calibration pressures were increased in steps of 100 psig to the upper limit and then decreased similarly until the last pressure was nominally that of the second of the calibration steps; i.e., 400, 500, 600, 700, 800, 700, 600, 500 psig. At the beginning of the calibration procedure the barometric pressure was observed using an aneroid barometer. The units of this observation were inches of mercury. This value was converted to psia and added to the pressures calculated for the deadweight tester.

Observations of the response voltages of the transducers were made by the data acquisition system after the operator was satisfied that the deadweight tester pressure had stabilized. This judgment was made by observation of the voltage from one of the transducers shown on the data logger display. At the operator's command, the data acquisition system took five successive observations of this set of voltages, computed and stored the means in a temporary disk file for later storage in the appropriate database. Table 8 lists the results of a typical calibration procedure.

Table 8. Calibration data for the static pressure transducers for August 9, 1985

	Time	Barometric Pressure		-- Deadweight Tester --			Total Pressure
		(mm Hg)	(psia)	Temp. (°C)	Mass (lb)	Pressure (psig)	(psia)
1	07:25:47	750.39	14.51	22.77	17.66622	399.913	414.302
2	07:26:55	750.39	14.51	22.77	22.08279	499.891	514.242
3	07:27:39	750.39	14.51	22.77	26.49982	599.880	614.192
4	07:28:16	750.39	14.51	22.77	30.91685	699.869	714.142
5	07:29:10	750.39	14.51	22.77	35.33348	799.849	814.083
6	07:29:50	750.39	14.51	22.77	30.91685	699.869	714.142
7	07:30:40	750.39	14.51	22.77	26.49982	599.880	614.192
8	07:31:27	750.39	14.51	22.77	22.08279	499.891	514.242

Table 8. Calibration data for the static pressure transducers for August 9, 1985 mean voltage observations -- Continued

	s/n 541529 (volts)	s/n 541528 (volts)	s/n 541530 (volts)	s/n 541532 (volts)	s/n 541533 (volts)
1	5.10530	5.19300	5.17212	5.17586	5.19856
2	5.89350	5.98574	5.96144	5.96800	5.99028
3	6.68946	6.78260	6.75612	6.76392	6.78780
4	7.48742	7.57816	7.55190	7.56182	7.58358
5	8.28862	8.37450	8.35012	8.36166	8.37990
6	7.49030	7.58196	7.55552	7.56610	7.58718
7	6.69326	6.78742	6.76104	6.76998	6.79204
8	5.89818	5.99190	5.96726	5.97466	5.99542

Static Pressure Transducer Location Key

Serial Number	Location
541529	Orifice Static Pressure
541528	Nozzle 1 Plenum Pressure
541530	" 2 " "
541532	" 3 " "
541533	" 4 " "

10. Transducer Response Functions and Coefficient Values

Upon completion of the observation sequences, the sets of response values for each transducer were combined with the corresponding pressure values to form data pairs for use in a least squares fitting procedure. Polynomial models having the transducer voltage response as the independent variable and the differential or static pressure as the dependent variable were used to interpolate through the range of the calibration data. Polynomials having degrees up to and including three in the voltage were fit to the calibrating pressure values for each transducer. The degree giving the best fit was selected for each, based on the reduction in the residual standard deviation relative to fits of lesser degree. In this way the degree of the polynomial used to represent the response of each transducer was determined. These procedures were conducted for the transducers when they were installed. All of the low range differential pressure transducer response functions were linear. The high range differential pressure transducer response functions were either quadratic or cubic depending on which of the three sets was in service. A single set of static pressure transducers was used throughout both seasons of data collection, and their response functions were quadratic in voltage.

As an example of the values of the transducer response function coefficients and the stability of the transducers over the course of a season of observations, the coefficients for one static and one differential pressure transducer are listed in tables 9 and 10. These values are typical of the calibration results and behavior of the transducers over the 3 to 4 month period of data collection.

Table 9. Transducer response coefficients for the orifice static pressure measurement transducer serial number 541529

Date	Time	--- Coefficients ---			Residual	Cal.
		Constant (psi)	Linear (psi/volt)	Quad. (psi/v^2)	Std. Dev. (psi)	Press. (psig)
07/25/85	10:09:07	-233.29	128.216	-0.205798	0.150	600.000
07/30/85	09:15:40	-233.41	128.029	-0.189999	0.237	600.000
07/31/85	08:07:53	-223.54	125.140	0.016461	0.357	640.000
08/01/85	09:05:39	-239.51	129.766	-0.311400	0.350	610.000
08/02/85	08:20:43	-237.51	129.072	-0.255183	0.169	620.000
08/05/85	07:51:01	-238.78	129.421	-0.285129	0.321	650.000
08/06/85	07:23:33	-236.17	128.639	-0.229388	0.271	600.000
08/07/85	07:44:56	-238.23	129.157	-0.265026	0.200	580.000
08/08/85	07:23:49	-229.40	126.590	-0.079266	0.208	575.000
08/09/85	07:31:27	-238.70	129.381	-0.285968	0.274	580.000
08/12/85	07:32:15	-232.91	127.651	-0.160128	0.290	585.000
08/13/85	09:45:02	-228.09	126.381	-0.078196	0.436	550.000
08/14/85	07:47:41	-234.65	128.058	-0.188498	0.288	545.000
08/15/85	07:59:50	-234.69	128.101	-0.195160	0.275	550.000
08/19/85	10:27:11	-238.15	129.148	-0.268495	0.309	510.000
08/21/85	07:20:26	-242.77	130.186	-0.330445	0.275	625.000
08/22/85	08:12:28	-242.74	130.261	-0.339371	0.204	620.000
08/23/85	10:50:09	-239.68	129.509	-0.294999	0.305	610.000
08/26/85	09:21:53	-237.16	128.716	-0.236816	0.208	615.000
08/27/85	09:04:39	-235.03	128.227	-0.208538	0.234	605.000
08/28/85	10:29:29	-235.90	128.457	-0.223505	0.237	630.000
08/29/85	10:59:11	-231.74	127.222	-0.137570	0.206	620.000
08/30/85	07:59:25	-242.72	130.231	-0.338824	0.234	595.000
09/03/85	07:41:23	-235.50	128.157	-0.201667	0.210	620.000
09/04/85	07:38:48	-235.84	128.225	-0.205099	0.239	640.000
09/16/85	07:56:08	-240.90	129.606	-0.301820	0.188	500.000
09/17/85	09:18:33	-237.99	128.852	-0.249666	0.555	670.000
09/18/85	09:13:19	-233.63	127.452	-0.143057	0.166	600.000
09/23/85	10:22:51	-230.62	126.663	-0.094247	0.232	710.000
09/24/85	07:00:01	-242.92	129.942	-0.314158	0.216	675.000
09/25/85	08:11:30	-234.01	127.469	-0.139353	0.272	670.000
09/27/85	08:23:51	-238.69	128.893	-0.248900	0.245	560.000
09/30/85	08:26:42	-227.44	125.606	-0.017610	0.242	565.000

Table 9. Transducer response coefficients for the orifice static pressure measurement transducer serial number 541529 -- Continued

Date	Time	--- Coefficients --- Constant (psi)	Linear (psi/volt)	--- Quad. (psi/v^2)	Residual Std. Dev. (psi)	Cal. Press. (psig)
10/01/85	11:11:30	-237.10	128.551	-0.226510	0.176	580.000
10/07/85	08:24:41	-234.10	127.738	-0.178850	0.307	680.000
10/08/85	07:55:09	-239.12	128.984	-0.257373	0.225	740.000
10/10/85	09:45:00	-240.43	129.421	-0.291259	0.468	670.000
10/18/85	08:42:44	-235.90	127.916	-0.187480	0.201	700.000
10/21/85	08:51:07	-235.84	128.060	-0.204891	0.347	700.000
10/22/85	10:46:05	-233.08	127.128	-0.131176	0.216	650.000
10/24/85	07:49:07	-237.95	128.523	-0.230499	0.363	710.000
10/25/85	09:00:43	-237.77	128.643	-0.246294	0.400	620.000
10/29/85	10:05:57	-237.08	128.361	-0.221312	0.405	670.000
10/30/85	08:29:23	-237.55	128.550	-0.237769	0.414	640.000
10/31/85	08:55:17	-235.09	127.738	-0.176185	0.288	600.000
11/01/85	11:12:27	-237.09	128.317	-0.221875	0.432	670.000
11/05/85	10:17:30	-234.22	127.420	-0.151916	0.158	550.000
11/06/85	09:28:05	-231.30	126.845	-0.126587	0.419	670.000
11/07/85	09:59:58	-232.12	127.018	-0.135807	0.412	630.000
11/11/85	09:08:01	-238.35	128.705	-0.243036	0.218	600.000
11/12/85	09:31:35	-235.60	127.897	-0.189424	0.153	620.000
11/15/85	08:51:53	-237.73	128.449	-0.226050	0.213	520.000
11/18/85	10:01:19	-236.28	128.008	-0.196398	0.225	685.000
11/19/85	09:48:00	-236.94	128.164	-0.206596	0.151	670.000
11/21/85	09:12:24	-235.08	127.683	-0.166131	0.164	500.000

Table 10. Response coefficients for differential pressure transducers HW-003 and HW-004

Date	Time	--- Coefficients ---		Residual Standard (psi)	Cal. Press. (psig)
		Constant (psi)	Linear (psi/volt)		
07/25/85	10:00:14	-0.3589	0.1807459	0.00036	600.000
07/30/85	09:09:07	-0.3579	0.1807354	0.00065	600.000
07/31/85	07:58:54	-0.3583	0.1807613	0.00027	640.000
08/01/85	08:45:24	-0.3574	0.1805631	0.00062	610.000
08/02/85	07:39:01	-0.3564	0.1806426	0.00082	620.000
08/05/85	07:41:36	-0.3577	0.1807001	0.00077	650.000
08/06/85	07:15:37	-0.3587	0.1808040	0.00030	600.000
08/07/85	07:34:31	-0.3583	0.1807104	0.00027	580.000
08/08/85	07:17:02	-0.3577	0.1807273	0.00038	575.000
08/09/85	07:22:02	-0.3596	0.1808294	0.00036	580.000
08/12/85	07:24:38	-0.3594	0.1807854	0.00032	585.000
08/13/85	09:37:34	-0.3580	0.1807022	0.00028	550.000
08/14/85	07:40:18	-0.3615	0.1807443	0.00025	545.000
08/15/85	07:53:10	-0.3580	0.1805939	0.00034	550.000
08/19/85	10:20:11	-0.3586	0.1807643	0.00024	510.000
08/21/85	07:13:27	-0.3572	0.1806690	0.00057	625.000
08/22/85	08:05:17	-0.3593	0.1807630	0.00073	620.000
08/23/85	10:42:43	-0.3580	0.1806722	0.00025	610.000
08/26/85	09:12:09	-0.3584	0.1807353	0.00056	615.000
08/27/85	08:56:11	-0.3587	0.1806638	0.00052	605.000
08/28/85	10:20:23	-0.3580	0.1807844	0.00026	630.000
08/29/85	10:50:33	-0.3577	0.1807424	0.00029	620.000
08/30/85	07:41:01	-0.3582	0.1807614	0.00039	595.000
09/03/85	07:33:03	-0.3611	0.1807606	0.00029	620.000
09/04/85	07:32:16	-0.3583	0.1807507	0.00019	640.000
09/16/85	07:40:58	-0.3593	0.1806250	0.00050	500.000
09/17/85	08:30:05	-0.3619	0.1807880	0.00042	670.000
09/18/85	08:59:57	-0.3627	0.1808188	0.00024	600.000
09/23/85	10:09:30	-0.3620	0.1808180	0.00026	710.000
09/24/85	06:45:59	-0.3609	0.1807562	0.00022	675.000
09/25/85	08:01:52	-0.3610	0.1807502	0.00033	670.000
09/27/85	08:09:02	-0.3602	0.1808493	0.00077	560.000
09/30/85	08:09:28	-0.3612	0.1807951	0.00040	565.000

Table 10. Response coefficients for differential pressure transducers HW-003 and HW-004 -- Continued

Date	Time	--- Coefficients --- Constant (psi)	Linear (psi/volt)	Residual Standard (psi)	Cal. Press. (psig)
10/01/85	10:54:28	-0.3618	0.1808015	0.00024	580.000
10/07/85	08:12:25	-0.3615	0.1807756	0.00047	680.000
10/08/85	07:44:03	-0.3617	0.1808452	0.00033	740.000
10/10/85	09:36:56	-0.3630	0.1807446	0.00028	670.000
10/18/85	08:26:16	-0.3617	0.1808375	0.00020	700.000
10/21/85	08:31:54	-0.3614	0.1808016	0.00030	700.000
10/22/85	10:29:35	-0.3623	0.1808268	0.00037	650.000
10/24/85	07:36:10	-0.3619	0.1808477	0.00034	710.000
10/25/85	08:45:58	-0.3611	0.1808794	0.00035	620.000
10/29/85	09:52:36	-0.3615	0.1807962	0.00021	670.000
10/30/85	08:16:28	-0.3620	0.1808396	0.00021	640.000
10/31/85	08:39:14	-0.3611	0.1807720	0.00030	600.000
11/01/85	10:59:36	-0.3615	0.1807993	0.00030	670.000
11/05/85	09:50:22	-0.3614	0.1807656	0.00031	550.000
11/06/85	09:08:12	-0.3702	0.1808140	0.00034	670.000
11/07/85	09:37:35	-0.3614	0.1808146	0.00029	630.000
11/11/85	08:42:34	-0.3615	0.1808274	0.00022	600.000
11/12/85	09:17:39	-0.3620	0.1808664	0.00022	620.000
11/15/85	08:28:56	-0.3625	0.1809411	0.00025	520.000
11/18/85	09:48:11	-0.3602	0.1808184	0.00025	685.000
11/19/85	09:33:02	-0.3619	0.1808329	0.00040	670.000
11/21/85	09:00:06	-0.3640	0.1811902	0.00148	500.000

11. Estimated Uncertainty in the Measurement of Orifice Meter Differential Pressures

The uncertainty in the estimate of the mean differential pressure value obtained from the array of 150 observations taken during a test run is the sum of the following components:

- the uncertainty in differential pressure working standard used in calibrating the transducers,
- the variability of the transducers as estimated by three residual standard deviations of the fitting procedure applied to the calibration data for each transducer, and
- the variation in the set of 150 observations of the differential pressure values as given by $s_{\Delta Pm}$, the standard deviation of the mean for the set, divided by the mean, expressed in percent.

The quantity $s_{\Delta P}$, the relative uncertainty in the observed differential pressure expressed in percent, may be expressed algebraically as

$$s_{\Delta P} = 0.018 + 3\ (s^2_{\Delta Pf} + s^2_{\Delta Pm})^{1/2}, \qquad (9)$$

where $s_{\Delta Pf}$ = residual standard deviation of the fit to the differential pressures used in calibrating the transducer for the test run of interest, divided by the mean differential pressure, expressed in percent.

12. Estimated Uncertainty in the Measurement of Orifice Meter and Critical Venturi Absolute Pressures

Estimates of the uncertainty in the mean absolute pressures measured in the four nozzle plenums and at the downstream tap of the orifice meter are composed of the following:

- the uncertainty in the pressures developed by the deadweight tester working standard used in calibrating the transducers,
- the variability of the transducers as estimated by three residual standard deviations of the fitting procedure, s_{Pf} applied to the calibration data for each transducer, divided by the mean differential pressure, expressed in percent,
- the uncertainty in the barometric pressure measurement, and
- the variation in the set of 150 observations of the static pressure values as given by s_{Pm}, the standard deviation of the mean for the set, divided by the mean, expressed in percent.

The relative uncertainty in the deadweight tester is taken as 98 parts per million, neglecting the small variation in the pressure dependence of the tare force component. The variability characteristic of each transducer is taken as three residual standard deviations of the fit used to estimate its coefficient values, corresponding to a 99% confidence limit. The uncertainty in the barometric pressure is taken as a constant value of 0.034 psia. The relative uncertainty in an absolute pressure measurement, s_P, for a test run is given in percent by

$$s_P = 98 \times 10^{-4} + \frac{3.4 \text{ (psia)}}{P} + 3 (s^2_{Pf} + s^2_{Pm})^{1/2}. \qquad (10)$$

13. Summary of Transducer Identifications and Measurement Parameters

Differential Pressure Transducers

Three sets of differential pressure transducers were used over the course of the project. Their designations and ranges are given below. These designations are stored in the database for each test run.

July 3 - November 11, 1984

Test Runs 1 - 403		Test Runs 500 - 970	
Serial Number	Pressure Range (in. of water)	Serial Number	Pressure Range (in. of water)
542130	0 - 40	542131	0 - 40
542131	0 - 40	610038	0 - 40
541822	0 - 200	606029	0 - 150
541823	0 - 200	606032	0 - 150

July 31, 1985 - November 19, 1985 -- Test Run Numbers 1 - 932

Serial Number	Pressure Range (in. of water)
HW-003	0 - 40
HW-004	0 - 40
HW-001	0 - 200
HW-002	0 - 200

Static Pressure Transducers

A single set of static pressure transducers were used throughout the project. The measured parameter was the same throughout.

Orifice Static Pressure - Serial Number 541529
Nozzle 1 Plenum Pressure - Serial Number 541528
Nozzle 2 Plenum Pressure - Serial Number 541530
Nozzle 3 Plenum Pressure - Serial Number 541532
Nozzle 4 Plenum Pressure - Serial Number 541533

E. Temperature Measurements and Uncertainties

Measurements of the flowing gas temperature were made using platinum resistance thermometers (PRT) mounted in high pressure, stainless steel thermometer wells. Each thermometer was of the four-wire type with one pair of leads used to carry the current and the second pair used for sensing the voltage developed across the platinum resistance element itself. Measurement of each thermometer's normal and reverse current resistance values were made using two channels of the data logger. The normal and reverse current resistance measurements obey the usual convention in which the normal resistance measurements are made using one pair of leads to carry the 1 milliampere current to the platinum resistance thermometer while the other set is used to sense the voltage developed across the resistance. The reverse current case merely reverses these functions. As a result the resistance of the thermometer's connection leads is eliminated if the resistance of the thermometer is taken as the mean of the normal and reverse current resistance values.

As a check on the resistance measurement function of the data logging equipment a precision, fixed resistor was connected to two of the channels and measured with each scan of the data logger. This value was also stored in the database as a check standard and a means of correction of the PRT resistance values should that be necessary.

1. Thermometer Location, Calibration, and Time in Service

During the course of the data collection seasons of 1984 and 1985 several sets of thermometers were used for measurement of the flowing gas temperature at the orifice meter location and in the nozzle plenums. Each of these sets was calibrated and the resulting coefficients used for computation of the temperature of the gas flowing through various portions of the test loop.

1984 Database Collection Configuration

For the 1984 data collection season, six PRT's were used. These were initially calibrated at NBS against a standards grade PRT. This thermometer had been calibrated against the national standards before being used for this particular calibration. Observations of the resistance of the six thermometers were made over the range of 50 to 120 °F. The temperature/resistance data pairs were fit to a linear model for use in computing temperature values from observation of the thermometer resistance when installed in the test loop. The locations and coefficients for the linear fits are given in table 11. Two thermometers were calibrated for use in the 6- and 10-inch orifice meters respectively. These were installed in both meters in the C section of the meter run approximately 5 diameters downstream of the orifice plate flange.

Table 11. Thermometer coefficients and locations for the 1984 database

	Location	Intercept (°F)	Slope (°F/ohm)
1	6-inch orifice meter	-429.826	4.61819
2	nozzle manifold position #1	-430.494	4.62398
3	nozzle manifold position #2	-429.362	4.61259
4	nozzle manifold position #3	-430.013	4.61871
5	nozzle manifold position #4	-430.569	4.62474
6	10-inch orifice meter	-430.323	4.62011

1985 Database Collection Configuration

Two sets of thermometers were used in the 1985 database collection activities. Neither was calibrated before the data collection procedures ended, but both were calibrated against the NBS national working standard PRT in 1986 prior to final computation of the results database from the observation database. Table 12 lists the thermometer coefficients, serial numbers, and locations for the first set of thermometers used. This set was used prior to October 2, 1985. Unfortunately, when the thermometers installed in the small nozzle manifold were removed, they were not marked as to location. Therefore, they were calibrated and the average value of the four was used in computing the nozzle plenum temperature for nozzles placed in that manifold.

The final set of thermometers was installed and used in database collection after October 2, 1985. This set was of the direct immersion type, i.e., inserted into the pipeline without a stainless-steel thermometer well.

Thermometer Calibration

Calibration procedures were performed on all thermometers used for temperature measurement by the NBS Pressure and Temperature Division using national working standards. The resistance of each thermometer was observed at three temperatures, nominally 50, 75, and 100 °F. The resistance value was measured using the four-wire method described above with a digital multimeter having 6 digits of resolution. The resistance-temperature data pairs for each thermometer were fit to a linear model of the form

$$T = A + BR$$

where T = temperature (°F), and
R = resistance (ohms).

The values for the intercept and slope obtained from the least squares fits for all thermometers are given, along with their location in tables 11, 12, and 13.

Table 12. Thermometer coefficients and locations for the 1985 database before October 2, 1985

	Location	Intercept (°F)	Slope (°F/ohm)	Serial Number
1	Orifice meter	-432.054	4.64166	213407
2	Lg. Manifold #1	-432.083	4.64336	213398
3	" " #2	-431.916	4.64189	213403
4	" " #3	-432.234	4.64382	213400
5	" " #4	-431.968	4.63854	213399
6	Orifice meter	-432.054	4.64166	213407
7	Sm. Manifold A	-431.943	4.63893	Average
8	" " B	-431.943	4.63893	"
9	" " C	-431.943	4.63893	"
10	" " D	-431.943	4.63893	"

Coefficient Values for Individual Thermometers Installed in Small Nozzle Manifold Before October 2, 1985

	Intercept (°F)	Slope (°F/ohm)	Serial Number
	-431.989	4.64032	209517
	-431.888	4.63723	209518
	-431.803	4.63732	209519
	-432.094	4.64086	209520
Mean	-431.943	4.63893	
S. D.	0.126	0.00193	

Table 13. Thermometer coefficients and locations for the 1985 database after October 2, 1985

	Location	Intercept (°F)	Slope (°F/ohm)	Serial Number
1	Orifice meter	-432.054	4.64166	213407
2	Lg. Manifold #1	-432.083	4.64336	213398
3	" " #2	-431.916	4.64189	213403
4	" " #3	-432.234	4.64382	213400
5	" " #4	-431.968	4.63854	213399
6	Orifice meter	-432.054	4.64166	213407
7	Sm. Manifold A	-431.674	4.63873	211186
8	" " B	-432.019	4.63834	213401
9	" " C	-432.083	4.64273	213406
10	" " D	-432.083	4.64194	213402

2. Temperature Measurement Uncertainty

The uncertainty in the measurement of the flowing gas temperature is composed of the uncertainty in the standard used to calibrate each thermometer, and the variation in the performance of each is quantified by the residual standard deviation to the linear model used to describe its response. The uncertainty in the standards used in calibrating these thermometers is 0.02 °F and should be considered systematic in effect. The residual standard deviation to the fit for all of the thermometers ranged from 0.04 to 0.05 °F. The larger of these two will be taken as the value characterizing the response of all of the thermometers. This uncertainty component will be taken as random in nature with three standard deviations, i.e., 0.15 °F, as the magnitude.

The resolution of the data logger limited the precision of the resistance value stored in the database and used to compute the mean value. Five digits of numerical precision were used, e.g., resistance values were stored as 103.52 ohms. The uncertainty due to the numerical precision of 0.01 ohm corresponds to 0.046 °F which is taken as a random effect.

An observation of the resistance of each of the five active thermometers is made with each scan of the data logger and stored in the observation database. The temperature value used in the computation of the gas properties necessary to compute the orifice discharge coefficient is the mean of these 150 observations. The variation in the discharge coefficient has contributions from the uncertainty in each thermometer's temperature value and from the uncertainty in the mean temperature value due to variability in the population of 150 observations. The population variability is obtained from three standard deviations of the mean value of each set of observations. The standard deviation of the mean value is taken as a random variation. Combination of these uncertainties or variabilities is performed by combining the random components in quadrature and the systematic components additively. The relative uncertainty, S_T, in percent in the temperature values is expressed as follows:

$$s_T = [(15/T)^2 + (3s_{Tm})^2 + (4.6/T)^2]^{1/2} + 2/T, \quad (11)$$

where s_{Tm} = standard deviation of the mean temperature divided by the mean temperature, expressed in percent, and
T = absolute temperature on the Rankine scale.

At a temperature of 75 °F (534.69 °R) having 0.25 °F as the value of s_{Tm}, the uncertainty in the measured value is 0.033%.

F. Natural Gas Composition Measurements - Gas Chromatography System

1. Chromatograph Description, Calibration Gas Composition, and Sample Gas-Handling Procedures

Calculation of the physical properties of the natural gas flowing through the test loop required measurement of its composition. An ENCAL gas chromatograph, manufactured by Electronic Associates, Inc. [12], and designed for natural gas pipeline measurement service, was installed for this purpose. The system consisted of a set of electrically operated valves, a temperature controlled chromatograph column/oven compartment, a thermal conductivity detector, and a control unit. The control unit could be programmed to calibrate the column and detector and to perform analyses at specified time intervals. When polled from the computer, the control unit transmitted the results of the most recent analysis to the computer for storage. Chromatographic analyses of the test loop gas were made at 13-minute intervals. This interval was used as the basic timing constraint for the test run timing. A data collection time of approximately 6 minutes was chosen to allow two successive test runs to be made between chromatograph analyses.

Gas analyses were based on calibration against standard gas mixtures. A total of four gas cylinders, two each of two compositions, were purchased for use as gas composition reference standards. These mixtures were specified to have compositions very near the average compositions of the two gas streams used in acquiring the flow test data. The composition and uncertainty for each mixture as specified by the manufacturer, Scott-Matheson [12], are given in table 14. Each of the gas samples was prepared gravimetrically and contained in 200 standard cubic foot pressure cylinders. The pressure of each cylinder was approximately 600 psig when delivered.

Calibration of the chromatograph was run automatically each night. The result of a calibration was a set of response factors which represented the ratio of the integrated output of a detected peak to the known concentration of a component in the standard gas. The information entered into the chromatograph controller for proper calibration were the composition of each component and its approximate elution time from the column. Because the system used a backflush method, the C6+ fraction was passed to the detector earliest, followed by nitrogen, methane, etc. The backflush time was also programmed into the control unit.

Sample or calibration gas must be maintained at a sufficiently high temperature to insure that all components are in the gas phase. Should this not be the case, the chromatograph column performance would vary over time, causing the component elution times to shift. In an extreme case, a component could be recognized as the preceding or subsequent component in the sequence. NGPL personnel at the Joliet test site took care to monitor the calibration behavior and adjust the timetable accordingly.

Table 14. Gas chromatograph reference gas sample composition

Amarillo Reference Gas

Component	Requested Conc. mole%	Variation tolerance ppm	Actual Concentration	
			mole %	mole %
N_2	2.700	100	2.7000	2.7010
CO_2	0.600	100	0.5989	0.5990
Methane	91.40	500	balance	balance
Ethane	3.750	100	3.7510	3.7576
Propane	1.000	100	1.0000	1.0010
Isobutane	0.150	20	0.1500	0.1500
n-butane	0.100	20	0.0998	0.1000
Isopentane	0.100	20	0.1000	0.1001
n-pentane	0.100	20	0.1001	0.1000
Hexane	0.100	20	0.1001	0.1001

Gulf Coast Reference Gas

Component	Requested Conc. mole%	Variation tolerance ppm	Actual Concentration	
			mole %	mole %
N_2	0.250	100	0.2501	0.2501
CO_2	0.600	100	0.6073	0.5990
Methane	96.50	500	balance	balance
Ethane	1.750	100	1.7490	1.7490
Propane	0.400	100	0.4003	0.4003
Isobutane	0.100	20	0.1000	0.1000
n-butane	0.100	20	0.0999	0.0999
Isopentane	0.100	20	0.0998	0.0999
n-pentane	0.100	20	0.1009	0.1001
Hexane	0.100	20	0.1005	0.1001

Like changing column performance, unknown changes in the calibration gas also may cause erroneous analyses. The most likely change occurs when the gas cylinder is allowed to cool to a temperature near or below the dew point of the heavier components, allowing them to wholly or partially condense. To avoid this situation, the calibration gas cylinders were enclosed in a thermostated cabinet located in the transducer room of the control shed. These metal, insulated cabinets were maintained near the set point of the thermostatically controlled heater (95 °F), thereby minimizing the possibility that separation occurred in the calibration gas cylinders.

Since the gas chromatograph was located in the control room of the instrumentation shed, the lines connecting it to the calibration gas cylinders and to the test loop were rather long. To eliminate the possibility of condensation of the heavier components, the connection lines from the thermostated cabinet and from the test loop sampling point were wrapped with electrically heated tape and insulated along their entire length. The set point temperature at which these lines were maintained was well above 100 °F.

The line from the test loop sampling point was fitted with a controlled leak downstream of the chromatograph inlet to insure sufficient flow in the sampling line and to have minimal delay between gas entry at the sampling point and arrival at the chromatograph sampling inlet. The test loop sampling point was located a short distance upstream of the Sprenkle flow conditioner of the orifice meter run. The pressure in the calibration gas and sample gas lines was regulated to 20 psig immediately upstream of the chromatograph inlet.

2. Gas Analysis Reproducibility

In terms of the heating value of the gas, the manufacturer's stated reproducibility for the chromatograph is plus or minus 1 BTU/standard cubic foot of gas. For the purpose of these tests, a more useful value is the compositional variation when a single sample is repeatedly analyzed. During studies of the reproducibility of the measurement systems used in this project, tests were run on the chromatograph to determine the effect on gas composition measurement of interchanging chromatograph calibration gases. Repeated analyses were made of samples of Gulf Coast gas. In the first case both calibration gas mixtures were used to calibrate the chromatograph. For the second case repeated analyses were obtained from a sample cylinder filled previously with Gulf Coast gas from pipeline shortly before the analyses were performed. Tables 15 and 16 give the results taken on October 16, 1985. The column headings of each analysis indicates the calibration gas used.

The first three analyses in table 15 were taken using the Gulf Coast calibration gas mixture to calibrate the chromatograph. Following these observations, the last four analyses were taken after calibrating the chromatograph using the Amarillo calibration gas mixture. The average specific gravity calculated by the chromatograph control unit was 0.58643 for the Gulf Coast gas and 0.58693 for the Amarillo gas. The respective standard deviations were 5.79×10^{-5} and 5.0×10^{-5}. The difference between these two averages, 0.00050, and their standard deviations is statistically significant. This implies that changing the reference gas has a small but detectable effect on the calculated specific gravity. The average calculated specific gravity for the seven analyses in table 15 taken as a group is 0.5867 with a standard deviation of 2.67×10^{-4}, corresponding to a 99% confidence limit of 0.14%. This uncertainty characterizes the maximum variation in measured gas composition. This gives a means to asses the random variation in gas composition obtained from the chromatographic system when used with a single standard mixture for calibration of the chromatograph as was done in the 1985 data collection period. Although there is a detectable shift in the chromatograph response, this shift will be treated as an instrumental variation in the error analysis.

The concentration observations given in table 16 were obtained immediately after obtaining the analyses given in the rightmost four columns of table 15, i.e., the chromatograph calibration coefficients are constant for these analyses. Therefore, these data are representative of the variation of repetitive concentration observations for one type of test gas using a specific calibration gas. The average calculated specific gravity for these analyses is 0.58689 with a standard deviation of 0.000038 corresponding to a 0.019% relative uncertainty at the 99% confidence level. The impact of this variation on computed density and critical flow factors for the sonic nozzles is discussed in more detail in Sections III and IV.

Table 15. Repeated analyses of blocked line containing containing gulf coast gas (composition in mole %)

Ref. Gas[a] /Comp.	Gulf	Gulf	Gulf	Amar	Amar	Amar	Amar
n-Hexane	0.02906	0.02946	0.02926	0.02937	0.02912	0.02906	0.02910
N^2	0.36384	0.36619	0.36057	0.34768	0.34613	0.34986	0.35015
Methane	95.6843	95.6770	95.6661	95.6118	95.6142	95.6058	95.6102
CO^2	0.69508	0.69276	0.69574	0.70943	0.70931	0.70977	0.70966
Ethane	2.31571	2.31875	2.32698	2.37820	2.37820	2.37853	2.37860
Propane	0.55849	0.56063	0.56356	0.56730	0.56510	0.56504	0.56497
i-Butane	0.14005	0.14008	0.14142	0.14032	0.13892	0.13979	0.13955
n-Butane	0.12443	0.12592	0.12680	0.12659	0.12790	0.12932	0.12889
i-Pentane	0.05607	0.05563	0.05475	0.05286	0.05710	0.05772	0.05680
n-Pentane	0.03296	0.03296	0.03478	0.03499	0.03315	0.03511	0.03392
Sp. Gr.	0.5864	0.5864	0.5865	0.5869	0.5869	0.5870	0.5869

[a] Gulf - gulf coast calibration gas
Amar - Amarillo " "

Table 16. Repeated analyses of gulf coast gas sample (composition in mole %)

Ref. Gas[a] /Comp.	Amar	Amar	Amar	Amar	Amar	Amar	Amar
n-Hexane	0.02278	0.02479	0.02578	0.02685	0.02761	0.02885	0.02902
N^2	0.44798	0.39926	0.37451	0.36632	0.36331	0.35495	0.35222
Methane	95.5366	95.5717	95.5983	95.6012	95.5962	95.6032	95.6091
CO^2	0.70705	0.70859	0.70737	0.70784	0.70888	0.70963	0.70962
Ethane	2.37331	2.37654	2.37427	2.37389	2.37983	2.37923	2.37566
Propane	0.56143	0.56233	0.56370	0.56457	0.56554	0.56487	0.56468
i-Butane	0.13807	0.13891	0.13926	0.13956	0.13933	0.13950	0.13978
n-Butane	0.12652	0.12733	0.12823	0.12877	0.12864	0.12882	0.12864
i-Pentane	0.05432	0.05711	0.05544	0.05712	0.05700	0.05714	0.05769
n-Pentane	0.03198	0.03339	0.03310	0.03388	0.03367	0.03383	0.03362
Sp. Gr.	0.5869	0.5869	0.5868	0.5869	0.5869	0.5869	0.5869

G. Orifice Meter Installation and Dimensional Measurements

The tests described here were run using 6- and 10-inch orifice meters also used in the intermediate Reynolds number project of the API orifice meter data base program [1]. Dimensional measurements of the orifice plates and meter tubes are described here and in the report of that project. The configuration of the meter tube/flow conditioners is similar to that of the other project. A 16-inch flow conditioner casing was built especially for use with the 10-inch meter runs in these tests but not used in the water project. The 10-inch flow conditioner used with the 6-inch meter tubes is a smaller version of the 16-inch conditioner.

The testing sequences in 1984 and 1985 were similar in that one 6- and one 10-inch meter tube were tested with all of the orifice plates for each meter size. During the 1984 data collection season the meter tubes designated FE-7ABC (6-inch) and FE-0ABC (10-inch) were used in gathering the test data. The FE-7ABC meter tube had not been used in the intermediate Reynolds number project at NBS-Gaithersburg prior to these tests. The surface finish had been measured previously while the meter tube was involved in testing performed at the NBS-Boulder laboratories [16]. The surface finish of the meter tube was 77 to 172 microinches rms. This value is well within the range specified by AGA Report No. 3 [5]. Subsequent to the tests and measurements reported in [16], the meter tube was involved in tests run at CEESI in early 1984. Prior to performing these tests the meter tube was brushed with a brass bristle brush of appropriate size. The interior surfaces of the meter tube sections had a light dusting of rust ascribed to the action of atmospheric condensation. This meter tube was inspected by Mr. Loy Upp, API-designated representative, and by Mr. G. G. Less, the NGPL project manager, and found acceptable for installation and testing with a surface finish within the upper range of surface roughness specified in AGA Report No. 3 [5].

The 10-inch meter tube FE-0ABC had been run previously in the intermediate Reynolds number project. The effects of surface corrosion on the interior of the meter tube sections were substantial. The surface roughness was judged to be outside the limits set in the standard procedures for orifice meter installation, AGA Report No. 3/API Measurement Standard 2530 [5]. As a result, considerable effort was expended removing the scaly corrosion from the meter tubes using stiff wire brushes and sandpaper. This treatment resulted in interior surfaces having a bright metallic color, being free of rust and well within the 300 microinch root-mean-square surface finish requirement as judged by Mr. Less.

The orifice meters tested during the 1985 data collection season were similar to those of 1984 with the exception that each of the meter tubes had been freshly honed. The honing restored the interior surfaces to surface roughness values well below the 300 microinch limit of AGA3/API 2530. Each meter tube was honed and its diameter measured at NBS-Gaithersburg before shipment to the Joliet test site. Measurements of the meter tube diameters were also made at the test site by NGPL personnel. A 6-inch nickel-plated meter tube, PE-8ABC, used in the intermediate Reynolds number project, was tested in the latter portion of the 1985 testing program. Surface finish measurements for these meter tubes are reported in [1] and were in the 100 to 250 microinch range. Surface finish measurements were made on all the tubes involved in this project and are reported in reference [1].

1. Orifice Meter Tube and Flow Conditioner Geometrical Characteristics and Dimensional Measurements

Conditioning of the flow immediately upstream of the meter tube assembly was done with the Sprenkle type [17] flow conditioners, which were used for all three projects in the orifice database program. Location of the flow conditioner/meter tube assembly was arranged to have the maximum distance downstream from the heater outlet. The arrangement of the meter runs in the test loop is shown schematically in Appendix A with pertinent installation information. The distance between the inlet to the flow conditioner and the heater outlet was approximately 89 feet.

High pressure casings for the flow conditioners were used for the six and 10-inch meter runs. The 6-inch casing was used in each of the three projects. A schematic diagram of the Sprenkle flow conditioner is given in reference [1]. The flow conditioner consists of three equally spaced plates. Each plate is perforated with a hexagonal hole pattern. The plates were welded to four rods symmetrically spaced around the circumference of the plates. The diameter of the plate/rod assembly was such that the assembly fit closely in its respective casing, forcing the flow through the plate perforations and only minimally along the periphery.

Orifice Meter Tube Geometry and Dimensional Measurements

The general geometry of each set of orifice meter tubes was the same. Three sections formed a set comprising a single meter tube, and 600 pound ANSI flanges were used in all tubes. The Sprenkle flow conditioner was bolted to the upstream flange of the approach tube, which was bolted to the upstream meter tube itself. The orifice plates were captured between the downstream flange of the upstream meter tube (length L_2) and the upstream flange of the downstream meter tube (length L_3). The arrangement of an orifice meter tube and a flange/meter tube section are shown schematically in figure 5. This diagram is labeled with several reference positions which were used for measurements of the meter tube diameters. As shown, two dowel pins were placed in each orifice meter flange. Additionally, the flanges joining the approach tube (length L_1) and the upstream meter tube were fitted with dowel pins. This was done to insure reproducible alignment of the approach tube and the upstream meter tube, and that the centerlines and circumferences of the two tubes were closely aligned. In this way any misalignment of centerlines between these tube sections was minimized.

Sealing at all flanges except the far upstream and downstream meter tube flanges was done with O-ring gaskets machined into each flange face. These are not shown in the diagram. This eliminated any interference that a normal insertion type gasket may have caused should it not have been positioned correctly.

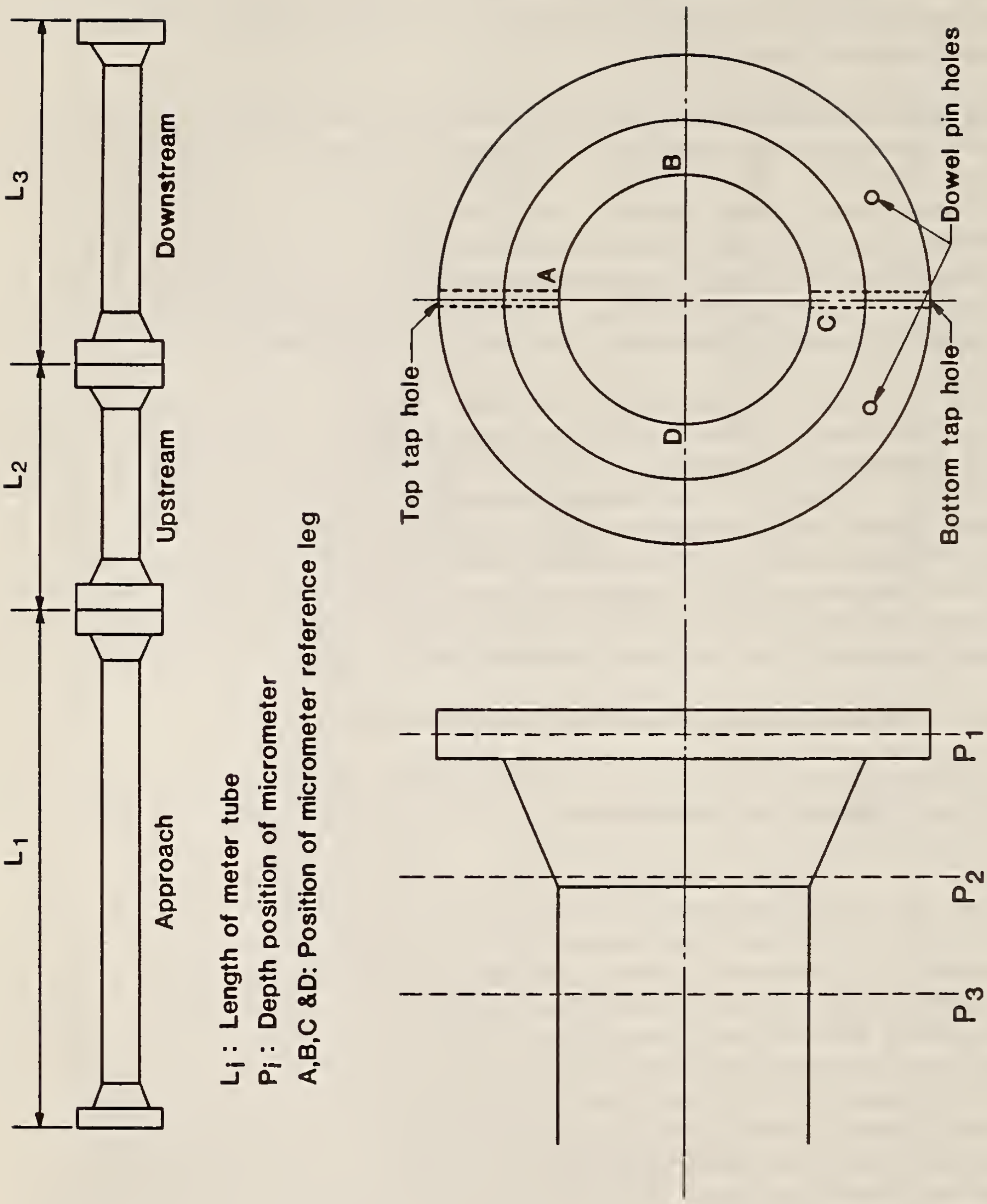

L₃
Downstream
L₂
Upstream
L₁
Approach
L_i : Length of meter tube
P_i : Depth position of micrometer
A,B,C &D: Position of micrometer reference leg
Top tap hole
A
B
C
D
Dowel pin holes
Bottom tap hole
P_1
P_2
P_3

Figure 5. Orifice meter tube dimensional measurement locations.

Also the distance between the orifice tap holes and the orifice plate faces were much more reproducible than would have been the case with gaskets. The flange pair at the upstream meter tube/approach tube combinations were sealed with orifice plates having bore diameter closely equal to the tube diameter, i.e., $\beta = 1.0$. These plate bores were within 0.002 inches of the meter tube diameter to minimize steps in the diameter profile of the meter tube set.

Dimensional Measurements of the Orifice Meter Tubes at NBS

The schematic diagrams in figure 5 indicate several reference positions and lengths associated with a meter tube set: the lengths of the three tube sections and reference positions associated with the diameter measurements. Diameter measurements were made with a set of internal micrometers of the type shown in the photograph in figure 6. This type of micrometer, designed for the measurement of cylindrical hole diameters, consists of three arms which center the micrometer in the cylinder to be measured. A small cylindrical rod, approximately 1.5 cm in length and 2 mm in diameter, forms the contacting surface at the tip of each micrometer's arm. The readability of each of the micrometers is 0.0001 inches (2.54 micrometers). Each micrometer of the set was adjusted to read directly using proving rings traceable to NBS length standards. The proving rings were also used to determine the reproducibility of diameters obtained using the micrometers once these were properly adjusted. Typical reproducibilities between operators was 0.0003 inches (7.62 micrometers) for diameters up to 6-inches. This decreased somewhat [0.0002 inches (5 micrometers)] for the smaller diameter meter tubes. For the 10-inch diameter meter tube the ability to reproduce diameter measurements was increased to approximately 0.001 inches (25 micrometers) due to the considerably increased difficulty in setting the micrometer lands in the meter tube in a reproducible manner.

Measurements made at NBS were made in the flow laboratory in which the temperature is approximately 20 °C. This value varies by 1-2 °C which introduces a 1-2 part per million systematic contribution to the total discharge coefficient error budget.

The procedure used to measure the diameter of the meter tube sections at the orifice flanges involved the four circumferential positions shown in figure 5, labelled A through D, and the three axial positions labelled P_1 through P_3. Although only the diameter near the centerline of the tap holes (position P_1) was used in the calculation of discharge coefficients (this being the customary position for stating the meter tube diameter), three positions along the length of each section were measured to characterize the contour of the tube near the orifice plate.

Measurement of diameters of both the upstream and downstream meter tubes were made. Position P_2 was located in the region of the weld between the flange and tubing/pipe forming the tube section. The fabrication of the meter tubes was such that the regions from the flange face to the center of the meter tube section had been ground to produce a smooth surface free from abrupt steps in the diameter. Position P_3 was located approximately one pipe diameter toward the interior of the meter section, from the weld. In most cases this position was approximately

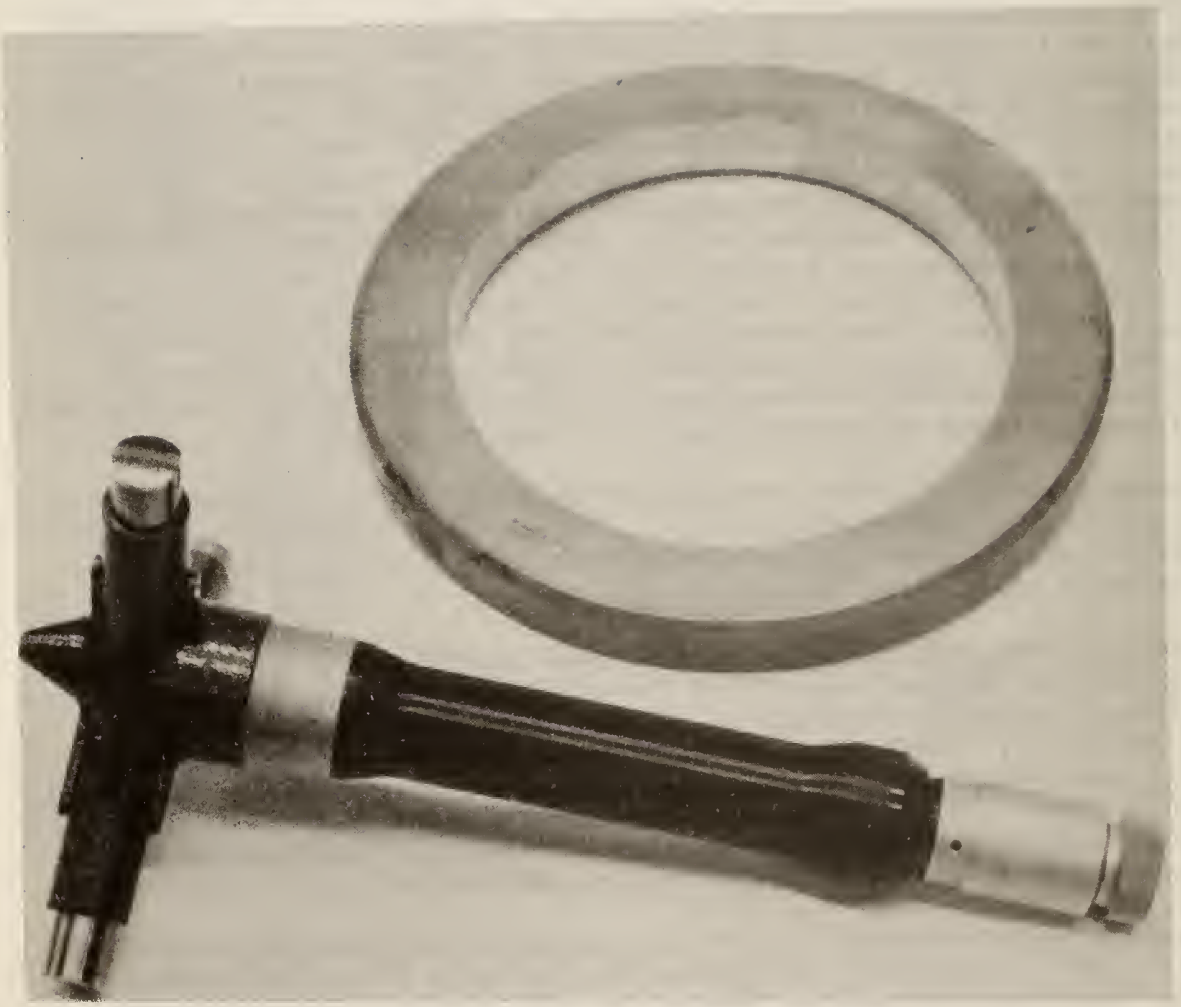


Figure 6. Photograph of internal micrometer with proving ring.

two pipe diameters from the flange face. Four measurements of the diameter were made at each of the three axial positions, except for the 10-inch meter tubes. Diameters were measured for the 10-inch meter tubes only at positions P_1 and P_2 because the micrometer could not be read reliably when placed in the third position. At each of these positions four observations of the diameter were made. One of the three arms of the micrometer was designated as the reference arm and was aligned with one of the four circumferential positions for each measurement. Out of roundness of the meter tube diameter may be detected in addition to obtaining four independent measurements of the diameter for that depth position. Position P_1 coincided with the centerline of the tap holes. To avoid the tap holes, measurements at positions A and C were made with the micrometer's reference arm positioned near the 1 and 7 o'clock positions, respectively. Measurement of the tap hole diameters and location relative to the flange were made. These measurements are described and the results given in the intermediate Reynolds number project report [1].

Meter Tube Diameter Measurements Made in 1984 and 1985

A series of measurements of the orifice meter tube diameters was made over the duration of the API program. Because of the corrosion problem encountered in the water flow testing of the Intermediate Reynolds Number project [1] and its subsequent investigation and solution, the diameter values of the meter tubes changed for the two years of testing reported in this project. Also the locations of the axial measurement locations changed somewhat.

The diameter measurement methods used in 1984 are similar to those described above with the exception of the 10-inch meter tubes. A two point diameter measurement was used for these tubes. The observation procedures resulted in diameter observations taken at each quadrant position at four, rather than three, axial positions for each of the upstream meter tubes. The axial positions used in 1984 were the following:

- immediately inside the face of the flange (tops of the lands flush with the flange face),
- 2 to 3 inches inside the flange faces
  2 inches for the 2- and 3-inch meter runs,
  2 1/4 inches for the 4- and 6-inch meter runs,
  3 inches for the 10-inch meter runs
- in the region of the tube/flange weld, and
- 8 inches from the flange face - 2- and 3-inch meter runs, 8 1/2 inches from the flange face - 4-, 6-, and 10-inch meter runs.

Although the conventional diameter value for calculation of discharge coefficients is that observed in the plane of the meter taps, this was not done in the early diameter measurements. The 1984 diameter values used in analysis of the data collected during that period used the mean diameter observed at position 1. All of the diameter values observed for meter tubes FE-0ABC and FE-7ABC are given in table 17. Measurements were made before and after running the 1984 tests for the 10-inch meter tube and are given in table 17.

Since the intermediate Reynolds number project was running concurrently with this one in 1984 and 1985, meter tubes were moved between the NBS Gaithersburg, MD site, NGPL in Joliet, IL, and CEESI in Nunn, CO. Diameter values differ from those used in the 1985 tests due to the need to recondition the meter tubes, i.e., remove rust from their interior surfaces.

The first tube to be tested at Joliet in 1984 was the 6-inch meter tube, FE-7ABC. This meter tube had been used in a set of NBS/CEESI tests done in the winter and spring of 1984 and was not tested in water flows until November 1984. Therefore, any level of rust in the meter tube at the time of the CEESI tests was due to atmospheric corrosion and judged to be minimal; however, the meter tube was brushed with a brass bristle brush immediately prior to installation and use in those tests. The diameters were measured upon return to NBS in November 1984.

The 10-inch meter tube, FE-0ABC, was tested at NGPL beginning on October 12, 1984. Its diameter was measured on March 5, 1984 at NBS Gaithersburg. It was run in the water flow measurement facility beginning in May 1984. Significant amounts of rust had formed during the water-flow tests, and before its installation at Joliet, it was brushed with 10-inch diameter steel brushes and lightly sanded by hand to restore its surface finish to an acceptable level as judged by the NGPL project manager. The meter tube was installed in the test run with no diameter measurements made after it was brushed.

Upon its return to the NBS-Gaithersburg site, diameter observations were made on January 23, 1985. These are tabulated in table 17. The values listed are the mean of the observers for each position in the case of multiple observers. The difference between the values observed in March of 1984 and January of 1985 differ insignificantly and are within the uncertainty of the measurement procedures used. Therefore, the value 10.020 inches is used as the diameter for analysis purposes.

Dimensional Measurements of the Orifice Meter Tubes at the Test Site

Measurements of the meter tube diameters were also performed at the test site by NGPL personnel using a commonly available two-point internal micrometer. Diameter measurements were made at the same three axial locations described in the previous section. Because the diameter measurements were taken with a micrometer which spanned the physical diameter of the meter tube, a different method of micrometer placement was used. The micrometer was positioned across four diameters of the tube. These were labelled H (horizontal), V (vertical), LV (left vertical), RV (right vertical). Tabulations of these measurements are given in table 18. A correction of -0.0006 inches was applied to the 6-inch meter tube measurements [18].

Table 17. Orifice meter diameter measurements made at NBS in 1984 and early 1985

Meter Tube Section FE-0B
Observation Date - March 5, 1984 Observers SW,GPB,JH

Position	A	B	C	D	Mean (inches)
1	10.020	10.020	10.020	10.021	10.020
2	10.023	10.022	10.022	10.021	10.022
3	9.999	10.005	9.998	10.004	10.002
4	10.005	10.019	10.005	10.021	10.012

Meter Tube Section FE-0B
Observation Date - January 23, 1985 Observer GPB

Position	A	B	C	D	Mean (inches)
1	10.019	10.020	10.020	10.020	10.020
2	10.026	10.024	10.027	10.025	10.026
3	10.004	10.011	10.007	10.017	10.010
4	10.006	10.007	10.018	10.026	10.014

Meter Tube Section FE-7B
Observation Date - November 11, 1984 Observer GPB

Position	A	B	C	D	Mean (inches)
1	6.0603	6.0585	6.0613	6.0622	6.0606
2	6.0582	6.0571	6.0556	6.0552	6.0565
3	6.0598	6.0686	6.0607	6.0569	6.0615
4	6.0629	6.0638	6.0610	6.0557	6.0608

Table 18. Orifice meter tube diameter measurements made by NGPL personnel at the Joliet test site prior to installation

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-7ABC
September 4, 1985

Meter Tube Section Lengths
FE-7A 209.75 in. FE-7B 53.9375 in. FE-7C 89.9375 in.

Diameter Measurements - Meter Section - FE-7B

Position	V	LV	RV	H	Mean	Corrected Mean
1	6.1205	6.1200	6.1209	6.1204	6.1204	6.1198
2	6.1200	6.1198	6.1201	6.1200	6.1200	6.1194
3	6.1199	6.1206	6.1201	6.1201	6.1202	6.1196

Diameter Measurements - Meter Section - FE-7C

Position	V	LV	RV	H	Mean	Corrected Mean
1	6.1193	6.1192	6.1190	6.1190	6.1191	6.1185
2	6.1203	6.1206	6.1187	6.1193	6.1197	6.1191
3	6.1200	6.1213	6.1180	6.1196	6.1197	6.1191

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-9ABC
July 18, 1985

Meter Tube Section Lengths
FE-9A 349.75 in. FE-9B 89.875 in. FE-9C 143.875 in.

Diameter Measurements - Meter Section - FE-9B

Position	V	LV	RV	H	Mean	Corrected Mean
1	10.0828	10.0822	10.0832	10.0823	10.0826	10.0826
2	10.0838	10.0828	10.0824	10.0835	10.0831	10.0831
3	10.0853	10.0848	10.0827	10.0856	10.0846	10.0846

Diameter Measurements - Meter Section - FE-9C

Position	V	LV	RV	H	Mean	Corrected Mean
1	10.0918	10.0918	10.0918	10.0913	10.0917	10.0917
2	10.0927	10.0916	10.0919	10.0922	10.0921	10.0921
3	10.0923	10.0913	10.0931	10.0899	10.0918	10.0918

Table 18. Orifice meter tube diameter measurements made by NGPL personnel at the Joliet test site prior to installation -- continued

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-9ABC
September 13, 1985

Meter Tube Section Lengths
FE-9A 349.75 in. FE-9B 89.875 in. FE-9C 143.875 in.

Diameter Measurements - Meter Section - FE-9B

Position	V	LV	RV	H	Mean	Corrected Mean
1	10.0813	10.0812	10.0815	10.0812	10.0813	10.0813
2	10.0827	10.0809	10.0837	10.0835	10.0827	10.0827
3	10.0827	10.0844	10.0857	10.0840	10.0842	10.0842

Diameter Measurements - Meter Section - FE-9C

Position	V	LV	RV	H	Mean	Corrected Mean
1	10.0915	10.0914	10.0913	10.0912	10.0914	10.0914
2	10.0896	10.0908	10.0899	10.0903	10.0902	10.0902
3	10.0872	10.0898	10.0862	10.0896	10.0882	10.0882

Orifice Meter Diameter Measurements For Meter Tube Assembly - PE-8ABC
November 4, 1985

Meter Tube Section Lengths
PE-8A 209.75 in. PE-8B 53.9375 in. PE-8C 89.9375 in.

Diameter Measurements - Meter Section - PE-8B

Position	V	LV	RV	H	Mean	Corrected Mean
1	6.0837	6.0806	6.0836	6.0830	6.0827	6.0821
2	6.0925	6.0915	6.0937	6.0967	6.0936	6.0930
3	6.0935	6.0852	6.0838	6.0840	6.0866	6.0860

Diameter Measurements - Meter Section - PE-8C

Position	V	LV	RV	H	Mean	Corrected Mean
1	6.0833	6.0894	6.0810	6.0823	6.0840	6.0834
2	6.0800	6.0845	6.0872	6.0924	6.0860	6.0854

As mentioned above, corrosion of the interior surfaces of the meter tube occurred during testing in the intermediate Reynolds number project [1]. All meter tubes were involved in test runs conducted in 1984 for that project. Investigation of the magnitude of surface roughness- induced effects due to corrosion were conducted between January and June of 1985. The meter tubes were refurbished by honing to remove the effects of corrosion. Honing enlarged the diameters of the meter tubes to a small degree. Tube diameter measurements were made after honing, which occurred in 1985. The results of these measurements are given in table 19. The meter tubes were plated with nickel using the electroless process. The nickel plating provided corrosion resistance to the water used as the flowing fluid in the intermediate Reynolds number project. As a test of the effects of the nickel plating on results obtained in this project, one of the 6-inch tubes, PE-8ABC, was tested in this project. The diameter measurements taken on it after plating are also included in table 19.

Table 20 lists measurements made at both NGPL and NBS (both years). The agreement between the two are quite good. The NBS values were used for computation of discharge coefficients and Reynolds number values, using the uncertainty estimates of the NBS measurements.

2. Orifice Plate Dimensional Measurements and Uncertainties

Orifice plate dimensional measurements were made at NBS only. The orifice diameter values used in this project are the same as those used in the intermediate Reynolds number project [1]. The reader is referred to the report of that project for the pertinent details of the measurement procedures and their results. The orifice diameters used in computing the discharge coefficient values reported later in this report are given with the listing of those results.

The room housing the measurement machine was maintained at 20 °C ± 0.5 °C during these measurements. The orifice plates were placed in the room at least overnight before making measurements.

Measurement of the orifice diameter used observation of three coordinate points approximately equally spaced around the orifice circumference. The measuring machine then fit these points to a circle to calculate the value for the diameter. Additionally, the coordinates of the center of the circle were calculated. This method was combined with three coordinate measurements along the outer circumference of the plate to determine the outer diameter and the position of the orifice center relative to the outside diameter of the plate.

Measurement of the plate flatness was done using several methods. All of these involved the observation of the height of the top surface of the plate. The patterns of the observations were all referenced to a line bisecting the orifice and handle of the orifice plate. Three observation procedures were used which differed in the number and location of the observations taken to determine the flatness of the plate. The details of the flatness observation procedures are listed below.

Table 19. Orifice meter tube diameter measurements after honing and before electroless nickel plating

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-7ABC
Surface Condition - BARE Observer - GPB Date 08/22/85

Meter Tube Section Lengths
FE-7A 209.750 in. FE-7B 54.000 in. FE-7C 90.000 in.

Diameter Measurements - Meter Section - FE-7B

Position	A	B (inches)	C	D	Mean
1	6.1200	6.1200	6.1200	6.1200	6.1200
2	6.1197	6.1196	6.1196	6.1197	6.1197
3	6.1198	6.1198	6.1198	6.1200	6.1198

Diameter Measurements - Meter Section - FE-7C

Position	A	B	C	D	Mean (inches)
1	6.1183	6.1185	6.1182	6.1184	6.1184
2	6.1195	6.1194	6.1195	6.1197	6.1196
3	6.1200	6.1198	6.1194	6.1198	6.1197

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-8ABC
Surface Condition - BARE Observer - GPB Date 07/01/85

Meter Tube Section Lengths
FE-8A 209.75 in. FE-8B 53.875 in. FE-8C 90.00 in.

Diameter Measurements - Meter Section - FE-8B

Position	A	B	C	D	Mean (inches)
1	6.0833	6.0833	6.0841	6.0861	6.0842
2	6.0823	6.0928	6.1039	6.0884	6.0918

Diameter Measurements - Meter Section - FE-8C

Position	A	B	C	D	Mean (inches)
1	6.0790	6.0846	6.0837	6.0838	6.0828
2	6.0860	6.0891	6.0812	6.0914	6.0869

Table 19. Orifice meter tube diameter measurements after honing and before electroless nickel plating -- continued

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-9ABC
Surface Condition - BARE Observer - GPB Date 05/13/85

Meter Tube Section Lengths
FE-9A 349.750 in. FE-9B 89.875 in. FE-9C 143.750 in.

Diameter Measurements - Meter Section - FE-9B

Position	A	B	C	D	Mean (inches)
1	10.0829	10.0829	10.0830	10.0829	10.0829

Orifice Meter Tube Diameter Measurements After Honing and Before Electroless Nickel Plating

Orifice Meter Diameter Measurements For Meter Tube Assembly - FE-0ABC
Surface Condition - BARE Observer - GPB Date 09/24/85

Meter Tube Section Lengths
FE-0A 349.625 in. FE-0B 89.875 in. FE-0C 143.750 in.

Diameter Measurements - Meter Section - FE-0B

Position	A	B	C	D	Mean (inches)
1	10.0246	10.0254	10.0266	10.0267	10.0258

Orifice Meter Tube Diameter Measurements After Electroless Nickel Plating

Meter Tube Section Lengths
PE-8A 209.75 in. PE-8B 53.875 in. PE-8C 90.00 in.

Meter Section - PE-8B

Position	A	B	C	D	Mean (inches)
1	6.0830	6.0815	6.0824	6.0847	6.0829
2	6.0809	6.0938	6.0774	6.0885	6.0852
3	6.0850	6.0883	6.0893	6.0823	6.0862

Diameter Measurements - Meter Section - PE-8C

Position	A	B	C	D	Mean (inches)
1	6.0778	6.0835	6.0843	6.0823	6.0820
2	6.0828	6.0895	6.0797	6.0891	6.0853
3	6.0911	6.0885	6.0829	6.0925	6.0888

Table 20. Orifice meter tube diameters in the plane of the tap hole centerlines (axial position 1)

-- NBS Measurements --		-- NGPL Measurements --	
Meter Tube	Diameter (inches)	Meter Tube	Diameter (inches)
FE-7ABC	6.0606 (1984) 6.1200 (1985)	FE-7ABC	6.1198
FE-8ABC	6.0840	FE-8ABC	
FE-9ABC	10.0829	FE-9ABC	10.0826 - 7/18/85 10.0813 - 9/13/85
FE-0ABC	10.020 (1984) 10.0258 (1985)	FE-0ABC	
PE-8ABC	6.0829	PE-8ABC	6.0821

Four Point Observation - Two pairs of observations were made along the bisection line on either side of the orifice. Of each pair one point was located near the orifice edge and the other near the periphery.

Twelve Pt. Observation - Four sets of three observations were made. Two sets were made along the bisection line as with the four point observation with the third point located midway between the orifice and plate edge. The remaining two sets were made in a similar way, but along the line perpendicular to the bisection line passing through the center of the orifice.

Eight Pt. Observation - This series of observations was the same as the twelve point series but with the middle point of each of the four sets eliminated.

Measurements of the orifice plates were made throughout the project. In most cases the initial measurements were made before the plate was involved in flow tests. In a few cases this occurred after flow testing. These measurements of the orifice diameter were the values used in computing the results of the tests. In approximately one-half of the dimensional measurements on the plates, the concentricity of the orifice and outer diameter of the plate was not determined. Since this is an important auxiliary parameter, i.e., one that directly influences the discharge coefficient, a confirmatory set of observations was made on the orifice plates. This series included

- the orifice diameter,
- the plate outer diameter,
- the concentricity of the orifice to the plate diameter,

- the flatness of the plate using the eight point observation method, and
- the thickness of the plate.

These measurements are given in the report of the intermediate Reynolds number project [1]. Measurements of edge sharpness were made using the lead foil technique. These are also described and the results given in [1].

Table 21 lists the results of the initial dimensional measurements on the orifice plates tested in this project. For those parameters not measured, the table entry is zero.

After the testing schedule had been completed in 1985, a set of measurements were made on all of the orifice plates used in the orifice test program. These measurements were designed to incorporate all of the dimensional measurement procedures for orifice plates discussed above. Table 22 lists the results of these measurements. In addition to the orifice plate involved in a series of measurements, a proving ring of diameter 3.39975 inches at 20 °C was used as a check of the performance of the multi-axis measuring machine. The proving ring's diameter was measured immediately before and after the sequence of measurements performed on the orifice plate. These values allow one to judge the reproducibility and accuracy of the measurements. These measurements are discussed in more detail in [1].

The quantities listed in table 22 include the following:

ID - orifice diameter,
OD - plate diameter,
Concentricity - the concentricity of the orifice relative to the plate outer diameter given as the x,y position of the orifice relative to a set of coordinates with origin defined by the center of the plate outer diameter, and
Ring Diameter - diameter of the proving ring, the first column is the initial result and the second column is the final result.
Flatness - given in terms of the flatness change over the orifice dam height, and normalized to the dam height.
Thickness - measured at four places around the circumference of the plate.

The flatness value for orifice plate FE-7/8-3A given here differs from that given in [1] due to a difference in the sequence of data collection procedures not detected until after publication of [1]. The flatness value given here is the result of additional analysis of the plate flatness measurement data and procedures for this plate.

Table 21. Orifice plate initial dimensional measurement results

Plate Ident.	Date	Orifice Diam. (in)	Obs.	Plate Diam. (in)	Obs.	Concentricity			Flatness (in)	Obs.
						Rad. (in)	Ang.	Obs.		
FE-7/8-1A	05/11/84	1.2494	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-2A	05/11/84	2.2498	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-2A	--	2.2501	1	0.0000		0.0000	0.0000		0.0000	0
Mean		2.5000								
FE-7/8-3A	--	3.0001	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-3A	05/11/84	3.0005	1	0.0000		0.0000	0.0000		0.0000	0
Mean		3.0003								
FE-7/8-4A	05/11/84	3.4979	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-4A	--	3.4990	1	0.0000		0.0000	0.0000		0.0000	0
Mean		3.3484								
FE-7/8-5A	05/11/84	3.9997	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-6A	05/11/84	4.4992	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-7A	02/07/84	0.6252	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-7A	05/11/84	0.6250	1	0.0000		0.0000	0.0000		0.0000	0
Mean		0.6251								
FE-7/8-8A	--	1.2503	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-1B	--	1.2496	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-2B	--	2.2499	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-3B	--	3.0004	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-4B	--	3.4999	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-5B	--	4.0002	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-6B	--	4.4997	1	0.0000		0.0000	0.0000		0.0000	0
FE-7/8-7B	02/07/84	0.6254	1	0.0000		0.0000	0.0000		0.0000	0
[a] FE-7/8-8B	06/13/86	0.6234	3	9.8731		0.0000	0.0017		0.0055	12
FE-7/8-1C	09/03/85	1.2499	3	0.0000		0.0000	0.0000		0.0037	12
FE-7/8-3C	09/03/85	2.9994	3	0.0000		0.0000	0.0000		0.0018	12
FE-7/8-5C	09/03/85	3.9994	3	0.0000		0.0000	0.0000		-0.0008	12
FE-9/0-1A	05/03/84	1.9987	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-2A	05/03/84	3.7480	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-3A	05/03/84	4.9985	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-4A	05/03/84	5.7488	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-5A	05/03/84	6.6241	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-6A	05/03/84	7.4996	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-7A	05/03/84	1.0001	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-1B	05/03/84	1.9983	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-2B	05/03/84	3.7480	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-3B	05/03/84	4.9976	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-4B	05/03/84	5.7488	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-5B	05/03/84	6.6239	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-6B	05/03/84	7.4997	1	0.0000		0.0000	0.0000		0.0000	0
FE-9/0-7B	05/03/84	0.9995	1	0.0000		0.0000	0.0000		0.0000	0

[a] This plate has a beta ratio similar to the 7B plate. It was a replacement for the FE-7/8-7A plate and marked as shown.

Table 22. Confirmatory plate diameter and flatness measurements
(All dimensional values given in units of inches)

Plate Design.	Date	ID	No. Obs.	OD	No. Obs.	Concentricity X	Y	Flat- ness	No. Obs.	-------- Thickness 1	2	3	------- 4	Ring Diameter		No. Obs.
FE-7/8-8A	07/17/86	1.2494	4	9.8701	4	0.0016	-0.0027	0.0004	12	0.1270	0.1270	0.1255	0.1250	3.3999	3.3998	4
FE-7/8-2A	07/17/86	2.2491	4	9.8746	4	-0.0034	-0.0125	0.0011	12	0.1170	0.1140	0.1175	0.1160	3.3999	3.3999	4
FE-7/8-3A	07/17/86	2.9984	4	9.8716	4	-0.0044	-0.0119	0.0016	12	0.1185	0.1175	0.1185	0.1190	3.3998	3.3999	4
FE-7/8-4A	07/17/86	3.4987	4	9.8737	4	-0.0033	-0.0129	-0.0002	12	0.1185	0.1180	0.1190	0.1195	3.4001	3.3999	4
FE-7/8-5A	07/17/86	3.9996	4	9.8726	4	-0.0026	-0.0132	0.0014	12	0.1170	0.1170	0.1170	0.1170	3.3999	3.3999	4
FE-7/8-6A	07/17/86	4.4988	4	9.8737	4	-0.0040	-0.0124	0.0014	12	0.1190	0.1180	0.1175	0.1160	3.3998	3.3998	4
FE-7/8-7A	09/09/86	0.6238	3	9.8732	4	0.0005	0.0010	0.0076	12	0.1250	0.1260	0.1250	0.1240	0.0000	0.0000	0
FE-7/8-8B	07/17/86	0.6241	4	9.8727	4	-0.0010	0.0010	-0.0057	12	0.1215	0.1220	0.1230	0.1220	3.3999	3.4000	4
FE-7/8-1C	07/17/86	1.2488	4	9.8730	4	0.0000	0.0030	0.0016	12	0.1210	0.1215	0.1220	0.1215	3.4000	3.3999	4
FE-7/8-2B	07/17/86	2.2488	4	9.8726	4	-0.0029	-0.0122	-0.0029	12	0.1190	0.1175	0.1180	0.1180	3.3999	3.3999	4
FE-7/8-3C	07/17/86	2.9989	4	9.8663	4	-0.0005	0.0069	-0.0026	12	0.1210	0.1210	0.1210	0.1210	3.4000	3.3998	4
FE-7/8-4B	07/17/86	3.4985	4	9.8713	4	-0.0049	-0.0119	0.0019	12	0.0000	0.0000	0.0000	0.0000	3.3999	3.3999	4
FE-7/8-5B	07/17/86	3.9989	4	9.8741	4	-0.0021	-0.0133	-0.0029	12	0.1170	0.1175	0.1187	0.1190	3.3999	3.3999	4
FE-7/8-6B	07/17/86	4.4990	4	9.8728	4	-0.0047	-0.0121	0.0058	12	0.1170	0.1175	0.1160	0.1175	3.3999	3.3999	4
FE-7/8-5C	07/17/86	3.9990	4	9.8673	4	-0.0011	0.0067	-0.0005	12	0.1220	0.1235	0.1260	0.1230	3.3997	3.3999	4
FE-9/0-1A	07/17/86	1.9991	4	14.2478	4	-0.0036	0.0005	-0.0029	12	0.2700	0.2690	0.2680	0.2730	3.3998	3.3998	4
FE-9/0-2A	07/17/86	3.7485	4	14.2485	4	-0.0045	0.0022	0.0048	12	0.2615	0.2640	0.2630	0.2640	3.4000	3.3998	4
FE-9/0-3A	07/17/86	4.9980	4	14.2477	4	-0.0043	0.0020	-0.0029	12	0.2625	0.2575	0.2580	0.2605	3.3997	3.3998	4
FE-9/0-4A	07/17/86	5.7492	4	14.2493	4	-0.0044	0.0014	-0.0084	12	0.2625	0.2575	0.2610	0.2630	3.3999	3.3996	4
FE-9/0-5A	07/17/86	6.6239	4	14.2481	4	0.0047	-0.0052	0.0033	12	0.2635	0.2675	0.2650	0.2675	3.3998	3.3996	4
FE-9/0-6A	07/17/86	7.4995	4	14.2481	4	0.0032	-0.0045	0.0019	12	0.2675	0.2670	0.2645	0.2640	3.3998	3.4000	4
FE-9/0-7A	07/17/86	0.9999	4	14.2512	4	-0.0021	-0.0028	0.0030	12	0.2600	0.2610	0.2625	0.2640	3.3999	3.3998	4
FE-9/0-7AR	07/17/86	0.9997R	4	1R4.2479R	4	-0.0009R	0.0015R	0.0078	12	0.2550R	0.2570	R0.2580R	0.2565	3.3999	3.3996	4
FE-9/0-1B	07/17/86	1.9980	4	14.2490	4	-0.0049	0.0007	-0.0067	12	0.2625	0.2545	0.2670	0.2680	3.3999	3.3998	4
FE-9/0-2B	07/17/86	3.7481	4	14.2492	4	-0.0047	0.0001	0.0045	12	0.2720	0.2670	0.2675	0.2665	3.3999	3.3999	4
FE-9/0-3B	07/17/86	4.9977	4	14.2508	4	-0.0056	0.0005	0.0037	12	0.2580	0.2570	0.2610	0.2590	3.3999	3.3999	4
FE-9/0-4B	07/17/86	5.7483	4	14.2504	4	-0.0065	0.0015	-0.0036	12	0.2650	0.2620	0.2650	0.2650	3.3998	3.3999	4
FE-9/0-5B	07/17/86	6.6229	4	14.2509	4	0.0031	-0.0052	0.0015	12	0.2630	0.2570	0.2650	0.2660	3.3998	3.3998	4
FE-9/0-6B	07/17/86	7.4987	4	14.2504	4	0.0041	-0.0054	-0.0029	12	0.2600	0.2580	0.2600	0.2600	3.3999	3.3999	4
FE-9/0-7B	07/17/86	0.9994	4	14.2516	4	-0.0032	-0.0019	0.0043	12	0.2630	0.2650	0.2670	0.2640	3.3998	3.3998	4

III. Calculation of the Mass Flow Rate of Natural Gas Through Critical Flow Nozzles and Natural Gas Physical Property Values and Their Uncertainty

Equations are presented in this section which were used to compute the mass flow rate through each of the critical flow nozzles used for a particular test run. These computations depend on experimental data (plenum static pressure, plenum temperature, and plenum gas composition) and on computations of the thermophysical properties of natural gas.

The equation developed by Starling, et al., as published in American Gas Association Draft Report No. 8 [2], was used to compute compressibility factors and sonic velocities. Called SUPERZ, this equation was supplied to NBS in FORTRAN code form. Extensions to the code allowed explicit calculations of enthalpy, entropy, density, temperature, and sonic velocity. The supplied code was converted to the Pascal programming language and modified to incorporate the required routines into the data reduction code for the data reported here. A routine called CSTAR was developed to compute the critical flow factor for natural gas. The algorithm and its application to the data reduction are described below.

A program known as TRAPP [3] was chosen as the method to calculate viscosities for the natural gas mixtures in this series of tests because it represented the state of the art in predictive codes for transport properties. Developed by Ely of the NBS in Boulder, CO, the program is based on a corresponding states model of fluid mixtures and is applicable to mixtures containing as many as 61 different constituents.

Every effort was made to maintain computational consistency throughout the sonic nozzle and orifice calculations. With the exception of viscosity, which was calculated with TRAPP, all fluid properties were calculated with SUPERZ. Comparisons of calculated and experimental values for both programs are presented at the end of this section. All computer programs were implemented on an IBM AT computer with a math coprocessor [12]. The internal resolution of the Pascal language implementation used was 11 significant digits. This was found to be satisfactory for all computations.

A. Derivation of Basic Equations for Gas Flow Rate Through Critical Flow Nozzles

Mass flow rate through an individual critical flow nozzle operating with sonic velocity in the throat may be computed from the following equation [9]:

$$\dot{m} = C_d A_t C^* P_p (RT_p)^{-1/2} \tag{12}$$

where $\dot{m}$ = mass flow rate,

C_d = discharge coefficient for nozzle,

A_t = area of nozzle throat,

C^* = critical flow factor for given conditions,

P_p = upstream or "plenum" pressure,

R = gas constant, and

T_p = absolute upstream or plenum temperature.

The critical flow factor, C^*, under assumptions defined below, is a function only of P_p and T_p. C^* is defined by [9]:

$$C^* = G_t \ (RT_p)^{1/2} / P_p, \tag{13}$$

where G_t is the ideal mass flux at the throat of the nozzle (mass per unit time per unit area), given by

$$G_t = \rho_t u_t, \tag{14}$$

where ρ_t is the mass density in the nozzle throat and u_t is the sonic velocity. Calculation of G_t is sufficient to determine the mass flow rate through the nozzle, but by convention the result is cast in the form of the C^* parameter.

The discharge coefficient C_d relates the performance of a given nozzle to a perfect critical flow nozzle. In contrast to orifice discharge coefficient values of approximately 0.6, critical flow nozzle values are generally 0.95 to 1.0. Therefore, when critical flow nozzles are used to measure mass flow rate, a much smaller "correction" is applied than that required for orifice plates to convert the "ideal" calculated mass flow rate to the true mass flow rate.

As described previously, the critical flow nozzles used in this work were calibrated in air by CEESI [8]. The nozzle discharge coefficients are given by

$$C_d = A + B \ R_d^{-1/2}, \tag{15}$$

where A and B are constants and R_d is the Reynolds number, defined as

$$R_d = \frac{48\dot{m}}{\pi d \mu_p} \tag{16}$$

where $\dot{m}$ = mass flow rate (lb/sec),
d = throat diameter of the critical flow nozzle (inches), and
μ_p = the viscosity of the gas based on plenum temperature and pressure conditions (lb/ft-sec).

Usually, the viscosity would be taken at the same point as the diameter to calculate the Reynolds number. The calibrations of the sonic nozzles performed by CEESI were based on the Reynolds number as defined by eq (15) because it contains only measured quantities or properties derived from measured quantities. Because the throat pressure and temperature for the critical flow nozzles are not measured during calibration, the plenum conditions are used to compute viscosity. Discharge coefficient fitting parameters for each of the critical flow nozzles were summarized in table 2.

When the mass flow rate is unknown, eq (12) to (16) are not explicit. The discharge coefficient depends on mass flow rate and the mass flow rate depends on the discharge coefficient. This implicit relationship is the situation for the data treated here. Once the ideal mass flux

(G_t) is determined for a nozzle, an iterative procedure must be used to determine the discharge coefficient, and then the true mass flow rate.

Certain assumptions are required to compute the mass flux or critical flow factor. The flow through the nozzle is taken to be isentropic and one dimensional, the plenum velocity is assumed to be zero, and the throat velocity is assumed to be that of the speed of sound in the gas for the throat conditions. These assumptions may be expressed as:

$$\Delta S = S_p - S_t = 0 \tag{17}$$

$$2\Delta H = 2(H_p - H_t) = u_t^2 \ , \tag{18}$$

where ΔS and ΔH are the entropy and enthalpy changes, respectively, from plenum to throat conditions, and u_t is the velocity at the nozzle throat. When an equation of state is available for the flowing fluid, eq (17) and (18) can be used to determine the mass flux and critical flow factor. For the reduction of the data described herein, the SUPERZ equation of state, described above, was used with algorithms developed at NBS to determine the critical flow factor and other fluid properties.

For the data reduction described here, no corrections were applied to account for nonzero plenum velocities. Because geometrical data for the nozzle manifolds were not available, and because these corrections to ΔH are very small, it is neither practical nor worthwhile to compute such corrections.

B. Derivation of Critical Flow Factor Equations

Equations (17) and (18) depend on the values of the density and temperature in the plenum and in the nozzle throat. With known (i.e., measured) values of the plenum properties, eq (17) and (18) constitute two simultaneous nonlinear equations for the density, ρ, and temperature, T, in the throat. These equations were solved using Newtonian iteration. The iterative process was continued until the relative errors between two successive throat densities and two successive throat temperatures were each less than 0.0025%. Once ρ and T in the throat were determined, they were used to compute the ideal mass flux at the nozzle throat and C^* by further computing the sonic velocity at throat conditions.

C. Description of Mass Flow Rate Algorithm to Compute Results for One Run

The input conditions to compute mass flow rate through all nozzles used for one test run were P_p, T_p, and the diameters for each nozzle. For a single test run, one to four nozzles were used in one or both manifolds. The individual flow rates were summed to obtain the total flow rate.

The iterative procedure used to compute C^* required many calls to fluid properties subroutines. The time required to converge to a solution depended on the number of iterations needed to satisfy the convergence criteria, which in turn depended on how close the initial estimates for the throat density and temperature were to the true throat density and temperature. When no other information was available, the ideal gas values were used as initial estimates [19]:

$$\rho_t = 0.65P_p \tag{19}$$

$$T_t = 0.83T_p . \tag{20}$$

With the ideal-gas starting values, about six iterations were required to obtain the throat density and temperature values to the specified numerical accuracy.

For those test runs that used several nozzles to achieve the required mass flow rate through the orifice meter, better initial estimates of the throat conditions were available. Since C^* depends only on the plenum conditions, test runs with several nozzles had plenum conditions (and, therefore, throat conditions) which were close for all nozzles in the test. Thus, once one nozzle in a test run or series of test runs was computed, the calculated throat conditions provided a better estimate of the throat conditions for the remaining nozzles than the ideal gas values. This was done when the plenum pressure and temperature were within an arbitrarily defined range of the previously computed nozzle. When the plenum pressure and temperature were within 1.5 and 0.5%, respectively, of the old values, faster convergence was obtained using the previously computed throat conditions in place of the ideal gas values. Computation times for the second and subsequent nozzles were typically halved relative to the first nozzle.

D. Comparison of Computed and Experimental Values

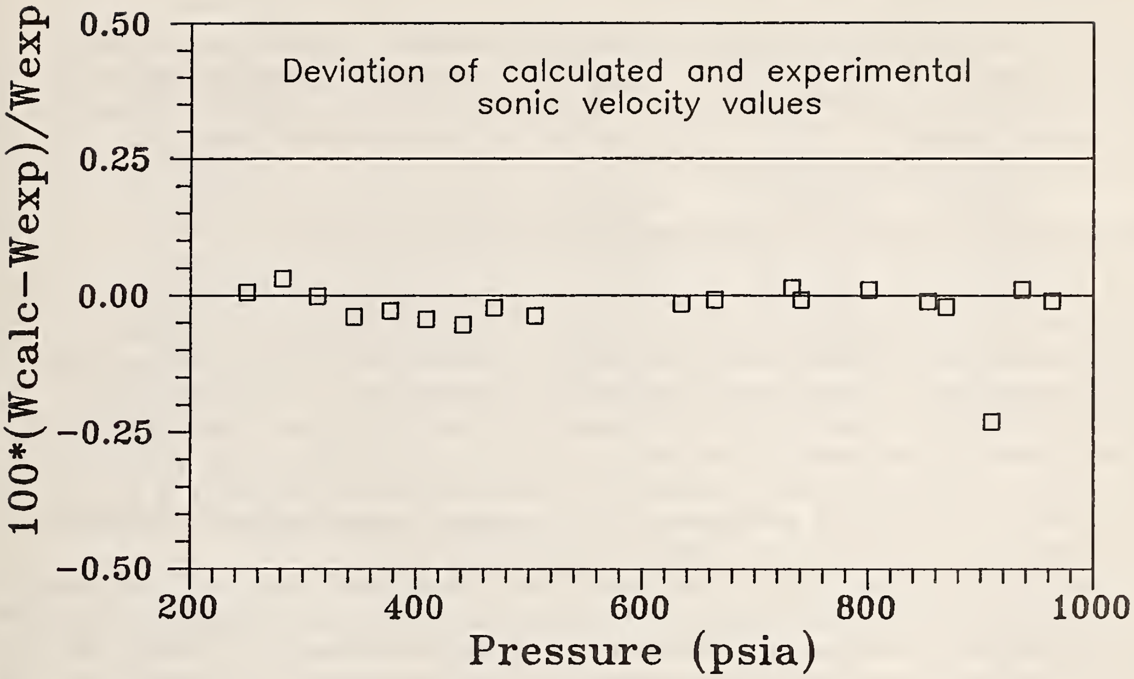
Several tests were run to determine the level of agreement of the codes developed for the final computations, done on 16 bit microprocessors, with the same calculations run on a mainframe computer. The computed results were also compared with sonic velocity and compressibility data obtained from samples of Gulf Coast and Amarillo gas.

Numerical Accuracy

A series of tests were run to compare the fluid property values obtained from the Pascal programs to those obtained from 14-digit mainframe computer computations. In all cases agreement was within the numerical accuracy of the 11 significant digits available from the Pascal language implementation used.

Comparison with Sonic Velocity Data

In addition to the numerical testing, data for sonic velocities in methane were obtained from the Gas Research Institute [20]. These data covered ranges of temperature and pressure of 193 to 423 K and 14.5 to 275 bar, respectively. Figure 7 illustrates the good agreement between the data and computations for temperatures above 400 °R (-59.69 °F) and pressures below 1000 psia. Except for one point (401.7 °R, 909.8 psi) which was outside the operating pressure range used at Joliet (480 to 750 psi), the maximum deviation was plus or minus 0.05%. Thus, over the



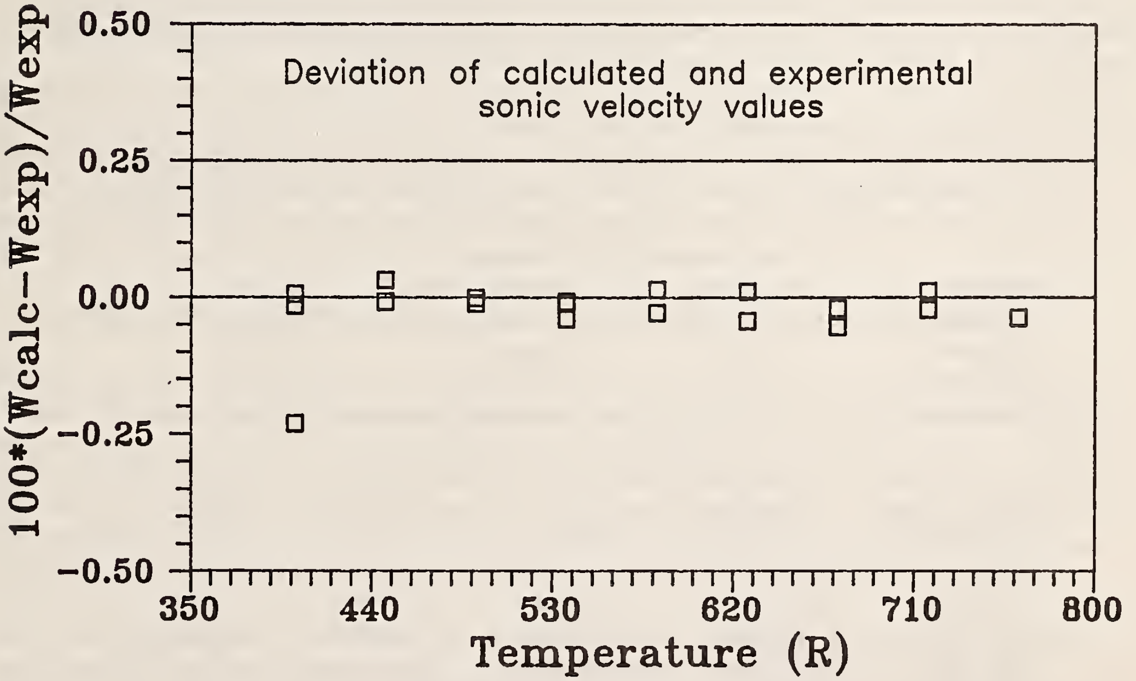


Figure 7. Comparison of experimental and calculated sonic velocity data.

entire range of conditions found in the course of the Joliet tests, the maximum error in calculated sonic velocity should be less than 0.05% and the average error less than 0.02%.

For these computational tests, the C6+ fraction was treated as n-hexane when calculating gas properties. Compared to expanding this fraction to account for C6, C7, and C8 alkanes, there is less than a 0.01% change in the computed density. This is indicative of the expected level of variation in the sonic velocity.

Comparison of Computed and Measured Compressibility Values

During the course of this project the API arranged for measurements to be made of the compressibility of a sample of Gulf Coast gas. These measurements were made at the University of Oklahoma using state-of-the-art PVT measurements in a modified Burnett apparatus. One of the two cylinders of chromatograph reference gas was used in these experiments. The experimental procedures and results were described in an unpublished report [21] to the API, part of which is reproduced in Appendix D of this report. These data were used to test the compressibility factors predicted by the equation of state of Starling, et al. [2].

Values of the compressibility factor were computed at two temperatures near 60 and 80 °F. These temperatures bounded the range over which the orifice discharge coefficient measurements were made. The maximum relative difference between the calculated and measured compressibility values is 0.041% (see table 23). The differences at the higher temperature are larger than those at the lower temperature and are taken as a conservative estimate of the error in the compressibility values needed to compute the gas density at the orifice and nozzles.

Table 23. Comparison of experimental and computed compressibility values for the gulf coast chromatograph calibration gas

Gas Composition (Mole %)

Methane	96.5016	Isopentane	0.0999
Ethane	1.7490	Pentane	0.0999
Propane	0.4003	Hexane	0.1001
Isobutane	0.1000	Nitrogen	0.2501
Butane	0.0999	Carbon Dioxide	0.5990

Compressibility Values

Temperature (Kelvin)	Pressure (Psia)	Z_{exp}	Z_{calc}	Dev. (%)
299.85	763.529	0.90644	0.90617	0.030
299.85	713.566	0.91223	0.91194	0.032
299.85	663.416	0.91818	0.91780	0.041
299.85	613.487	0.92391	0.92370	0.022
299.85	563.554	0.92986	0.92967	0.020
299.85	513.613	0.93581	0.93570	0.012
299.85	463.741	0.94210	0.94177	0.035
299.85	413.745	0.94798	0.94790	0.008

Table 23. Comparison of experimental and computed compressibility values for the Gulf Coast chromatograph calibration gas -- Continued

		Compressibility Values		
Temperature (Kelvin)	Pressure (Psia)	Z_{exp}	Z_{calc}	Dev. (%)
288.71	763.416	0.89072	0.89084	-0.013
288.71	713.719	0.89766	0.89762	0.004
288.71	663.742	0.90454	0.90452	0.002
288.71	613.791	0.91148	0.91148	0.000
288.71	563.820	0.91855	0.91849	0.006
288.71	513.860	0.92541	0.92556	-0.016
288.71	463.892	0.93258	0.93267	-0.010
288.71	413.921	0.93978	0.93983	-0.005
288.71	363.987	0.94698	0.94701	-0.003

E. Effect of Compositional Uncertainty on Computed Values

In section II it was shown that the random uncertainty in the chromatographic analysis of composition was plus or minus 0.01% of the computed specific gravity. In section IV we will develop numerical estimates of the uncertainty in computed density and critical flow factor using the known uncertainties in composition.

F. Uncertainty in Natural Gas Density and Critical Flow Factor Due to Temperature and Pressure Uncertainties

The effects of pressure and temperature uncertainties on the computation of the critical flow factor and gas density values may be analyzed numerically. Numerical estimates of the partial derivatives of density and critical flow factor with respect to pressure, temperature, and composition are computed in section IV and used to compute estimates of the density and critical flow factor uncertainties.

G. Determination of Viscosity for Calculation of Reynolds Number

Values of the real gas viscosity were needed to compute Reynolds numbers of the flowing gas. Throat Reynolds numbers based on plenum conditions were used to correlate the sonic nozzle discharge coefficients. Values of the viscosity were required for the range of conditions downstream of the orifice plates and upstream of the sonic nozzles. These conditions ranged from 450 to 750 psia and from 510 to 560 °R. The TRAPP program described above was used to compute the required viscosity values.

The average temperature and pressure for the orifice and each nozzle were computed for each test run. These were combined with the gas composition for the run, and TRAPP was used to compute viscosities for the orifice and the four nozzles. These values were combined with appropriate identifying information to form a table for each test run. At the time the results for the test run were computed, this table was used to obtain the viscosities used in the analysis of test run results.

IV. Calculation of the Uncertainty in the Orifice Discharge Coefficient Values Using the Propagation-of-Errors Method

An estimate of the uncertainty in the orifice discharge coefficient depends on the combined uncertainties in the independent parameter values on which it depends. Equation (1) indicated these explicit dependences:

$$C_d = \frac{\dot{m}(1-\beta^4)^{1/2}}{Nd^2YF_a(\rho\Delta P)^{1/2}},$$

where C_d = orifice discharge coefficient,
$\dot{m}$ = total mass flow rate through the orifice,
d = diameter of the orifice,
N = a constant whose value depends upon the units of the measured parameters,
ρ = density of the flowing fluid, gas in this project,
Y = adiabatic expansion factor,
F_a = orifice thermal expansion factor,
ΔP = the differential pressure developed across the orifice meter,
β = d/D, the beta ratio, and
D = the diameter of the meter tube.

In previous sections we developed algebraic expressions for the relative uncertainties in each of the various measurands. These components are combined here to derive the relative uncertainty in the discharge coefficient resulting from the propagation of errors in the observed parameters.

As in the development of the uncertainty for each observed parameter, the random error components are combined in quadrature and the systematic components additively. For the total relative uncertainty in the discharge coefficient expressed in percent, denoted by s_{C_d}, one has the general expression

$$s_{C_d} = \left\{ \sum_j \left[\frac{Y_j}{C_d} \frac{\partial C_d}{\partial y_j}\right]^2 s_{jr}^2 \right\}^{1/2} + \sum \left|\frac{Y_j}{C_d} \frac{\partial C_d}{\partial y_j}\right| |s_{js}|, \qquad (21)$$

where y_j = jth parameter in eq (1),
s_{jr} = random uncertainty in percent for the jth parameter relative to that parameter,
s_{js} = systematic uncertainty in percent for the jth parameter relative to that parameter.

The following describes the individual uncertainties that contribute to the uncertainty in the discharge coefficient.

A. Analysis of the Total Mass Flow Rate Measurement Uncertainty

The total mass flow rate through the system, and hence the orifice meter, is the summation of the mass flow rates through the individual nozzles. The mass flow rate through a single critical nozzle is determined by the pressure, temperature, and composition of the gas and the calibration of the nozzle embodied in eq (2). The uncertainty in this mass flow rate depends on the uncertainties in these parameters and on the computed values of the gas properties. The following analysis first develops an algebraic expression for the uncertainty in the total mass flow rate through the system in terms of the uncertainties in the mass flow rates through the individual nozzles. It then develops an expression for the total uncertainty in the mass flow rate through a single critical nozzle.

1. Uncertainty in the Total Mass Flow Rate Through the Orifice

The total mass flow rate through the orifice, $\dot{m}$, is the sum of the mass flow rates through the individual critical nozzles:

$$\dot{m} = \Sigma\, \dot{m}_i ,$$

where $\dot{m}_i$ is the mass flow rate through the ith nozzle and the sum is over the total number of nozzles operating in a test run. Combination of the relative uncertainties in the mass flow rates from the individual nozzles to form the relative uncertainty in percent in the total mass flow rate through the system, denoted by $s_{\dot{m}}$, requires, as above, that the random errors be combined in quadrature and that the systematic errors be combined additively. In analogy with eq (21), this leads to the expressions

$$s_{\dot{m}} = s_{\dot{m}r} + s_{\dot{m}s}$$

$$s_{\dot{m}r} = \left[\Sigma\, (\dot{m}_i/\dot{m})^2 (s_{\dot{m}_i r})^2\right]^{1/2}$$

$$s_{\dot{m}s} = \Sigma\, (\dot{m}_i/\dot{m}) \left|(s_{\dot{m}_i s})\right| ,$$

where $s_{\dot{m}_i r}$ ($s_{\dot{m}_i s}$) is the random (systematic) contribution to the relative error in percent in the mass flow rate through the ith nozzle.

2. Uncertainty in the Mass Flow Rate Through a Single Critical Nozzle

The mass flow rate through a single nozzle was given in eq (2):

$$\dot{m}_i = PA_t C^* C_d/(RT)^{1/2},$$

where P = nozzle plenum pressure value,
A_t = throat area of the nozzle,
C^* = critical flow factor for the gas,
C_d = nozzle discharge coefficient,
R = gas constant, and
T = nozzle plenum temperature.

The random and systematic relative uncertainties in the mass flow rate through the ith nozzle, in percent, are given by

$$s_{\dot{m}_i r} = \left\{ \sum_j \left(\frac{y_j}{\dot{m}_i} \frac{\partial \dot{m}_i}{\partial y_j} \right)^2 s_{jr}^2 \right\}^{1/2}$$

$$s_{\dot{m}_i s} = \sum_j \left| \frac{y_j}{\dot{m}_i} \frac{\partial \dot{m}_i}{\partial y_j} \right| |s_{js}|,$$

where here y_j is the jth parameter in the equation for $\dot{m}_i$, and s_{jr} (s_{js}) is the random (systematic) uncertainty in the jth parameter, divided by that parameter, expressed in percent.

Computational methods and numerical estimates of the relative uncertainties in each observed or computed parameter were given in previous sections of this report. These are now collected for use in the expression for the uncertainty in the mass flow rate through a single nozzle.

Mean Absolute Pressure

Equation (10) gave s_p, the relative uncertainty in percent in the observed plenum pressure of each nozzle. The random and systematic contributions were the following:

$$s_{Pr} = 3\ (s_{Pf}^2 + s_{Pm}^2)^{1/2}$$

$$s_{Ps} = 98 \times 10^{-4} + \frac{3.4 \text{ psia}}{P}, \tag{22}$$

where s_{Pf} is the residual standard deviation of the fit used to determine the absolute pressure transducer response coefficients, divided by the mean pressure, expressed in percent, and s_{Pm} is the standard deviation of the mean pressure for the observations taken during the test run, divided by the mean pressure, expressed in percent.

Mean Temperature

Equation (11) gave s_T, the relative uncertainty in percent in the mean plenum temperature. The random and systematic components were

$$\begin{aligned} s_{Tr} &= [(15/T)^2 + (3s_{Tm})^2 + (4.6/T)^2]^{1/2} \\ s_{Ts} &= 2/T, \end{aligned} \qquad (23)$$

where s_{Tm} is the relative standard deviation of the mean absolute temperature value in °R expressed in percent.

Nozzle Discharge Coefficient

The relative uncertainty in percent in the discharge coefficient for a single nozzle depends on the throat diameter of the nozzle. The random and systematic contributions were given in section II.C as

$$\begin{aligned} s_{C_d r} &= \left\{\left[3s_{C_d f}\right]^2 + 17 \times 10^{-4}\right\}^{1/2} \\ s_{C_d s} &= 0.22 + 0.15 \cdot k. \end{aligned} \qquad (24)$$

where k = 0 for nozzle diameters of 0.5328 inches or less and k = 1 otherwise. $s_{C_d f}$ is the standard deviation of the fit used to determine C_d as a function of Reynolds number, divided by C_d, expressed in percent (see table 2).

Nozzle Throat Area

Because the temperature of the nozzle during calibration was not the same as its temperature during test runs, there was a systematic uncertainty in the nozzle throat area, $S_N A$, due to thermal contraction and expansion. The area of the nozzle throat is proportional to the square of the nozzle diameter, d, given by

$$d = d_o \; (1 + \alpha \Delta T),$$

where d_o is the diameter of the nozzle during calibration, α is the linear thermal expansion coefficient, and ΔT is the difference between the nozzle temperature during a test run and that at similar conditions,i.e., throat Reynolds number, during calibration with air as the working fluid.

Uncertainties in nozzle area would not propagate if ΔT were zero and d_o were used to compute discharge coefficients and experimental mass flow rates. However, ΔT was not zero in general, and one must estimate its effect on nozzle throat area. The term ΔT can be bounded and its sign determined by comparing the conditions at the time of nozzle calibration to the conditions at run time.

The effective temperature of the nozzle is bounded by the plenum gas temperature and the throat gas temperature. The actual temperature depends on the details of the heat transfer between the flowing gas and the nozzle and between the nozzle and its surroundings. Because the velocity of the gas varied substantially from the plenum to the nozzle throat, the heat transfer coefficient varied appreciably along the entire inner surface of the nozzle. This heat transfer problem was not sufficiently well-defined for the conditions encountered in this project to be considered a viable approach for estimation of the effective nozzle temperature.

Our approach was to establish bounds for the effective nozzle temperature and to combine these with data from the air calibrations to compute bounds for ΔT. These values were then used to compute the uncertainty in the nozzle throat area. This uncertainty was added as a systematic term to the uncertainty expression for the mass flow rate.

For the NGPL tests in natural gas, the throat temperature varied from 437 to 492 °R, and the plenum temperature from 510 to 570 °R. For the nozzle calibrations in air, the corresponding ranges were 403 to 440 °R and 485 to 532 °R. The difference between the throat temperature (plenum temperature) during test runs and that during calibration is denoted by ΔT_t (ΔT_p).

The average temperatures for the calibrations, performed using air as the flowing fluid, were lower than those for the natural gas tests, but the effective nozzle temperature during test runs could be lower than, higher than, or equal to the effective nozzle temperature at calibration. A case-by-case approach was used to determine the possible systematic errors. If ΔT_t and ΔT_p had the same sign, ΔT was equated to the larger of the two; if ΔT_t and ΔT_p had opposite signs, both positive and negative uncertainties in the nozzle area were computed.

As an example, let us compare data obtained in test runs in natural gas for the 0.5328 inch nozzle to air calibration data obtained at CEESI. [The mean air temperatures are used for each nozzle as there was little variation in air temperature (mean variation = 5.4 °R) for each specific nozzle calibration.] The throat temperature at NGPL was 465 °R and at CEESI 430 °R, and the corresponding plenum temperatures were 542 °R and 520 °R. Thus, in this case $\Delta T_t = 35$ °R and $\Delta T_p = 22$ °R. Taking the larger of these as the worst case estimate of ΔT, one obtains the following estimate of the run-time throat diameter:

α = coefficient of thermal expansion = $8\text{x}10^{-6}$ in/in °R,
$\alpha\Delta T = 8\text{x}10^{-6} \text{ x } 35 = 2.8\text{x}10^{-4}$ in/in, and
$d = d_o \ (1 + \alpha\Delta T) = 0.5328(1 + 2.8\text{x}10^{-4}) = 0.532949$ inches,

where the value of d_o is from table 2. This corresponds to a relative uncertainty in nozzle area of +0.056%. In this example, there is no additional uncertainty in the throat area in the negative direction. Similar calculations were made for each nozzle of a test run and an appropriate directional systematic error component was included in the error budget for the mass flow rate.

Critical Flow Factor and Density for Natural Gas

Uncertainties in the critical flow factor contribute to the uncertainty in the mass flow rate through a single nozzle. Uncertainties in the density of the natural gas do not, but they do contribute to the error budget for the orifice discharge coefficient. Because the analysis of these two sources of uncertainty are similar, they are considered together. The critical flow factor and density depend on three variables: P, T, and $\underline{x}$, where $\underline{x} = (x_1, x_2, \ldots, x_n)$ is the vector of mole fractions for any given case. The total random and systematic relative uncertainties in these quantities in percent are given by

$$s_{C^*r} = \left\{ \left(s_{Pr} \frac{P}{C^*} \frac{\partial C^*}{\partial P} \right)^2 + \left(s_{Tr} \frac{T}{C^*} \frac{\partial C^*}{\partial T} \right)^2 + \sum_j \left(s_{x_j r} \frac{xj}{C^*} \frac{\partial C^*}{\partial x_j} \right)^2 \right\}^{1/2} \tag{25}$$

$$s_{C^*s} = |s_{Ps}| \left| \frac{P}{C^*} \frac{\partial C^*}{\partial P} \right| + |s_{Ts}| \left| \frac{T}{C^*} \frac{\partial C^*}{\partial T} \right| + \sum_j \left(|s_{x_j s}| \left| \frac{xj}{C^*} \frac{\partial C^*}{\partial x_j} \right| \right) \tag{26}$$

$$s_{\rho r} = \left\{ \left(s_{Pr} \frac{P}{\rho} \frac{\partial \rho}{\partial P} \right)^2 + \left(s_{Tr} \frac{T}{\rho} \frac{\partial \rho}{\partial T} \right)^2 + \sum_j \left(s_{x_j r} \frac{xj}{\rho} \frac{\partial \rho}{\partial x_j} \right)^2 \right\}^{1/2} \tag{27}$$

$$s_{\rho s} = |s_{Ps}| \left| \frac{P}{\rho} \frac{\partial \rho}{\partial P} \right| + |s_{Ts}| \left| \frac{T}{\rho} \frac{\partial \rho}{\partial T} \right| + \sum_j \left(|s_{x_j s}| \left| \frac{xj}{\rho} \frac{\partial \rho}{\partial x_j} \right| \right) \tag{28}$$

where $s_{x_j r}$ = the random relative uncertainty in gas component x_j concentration, and
$s_{x_j s}$ = the systematic relative uncertainty.

To estimate the uncertainties in critical flow factor and density, the partial derivatives have to be estimated numerically and combined with the estimated uncertainties in the pressure, temperature, and mole fractions.

Values of partial derivatives with respect to each mole fraction, pressure, and temperature were computed using a perturbation method and the equation of state. The partial derivatives all reached their (relative) maximums at the same combination of pressure, temperature, and mean composition: 815 psia, 510 °R, and Gulf Coast gas. These values of pressure and temperature are reasonable because fluid properties are always most sensitive to system variables at the highest pressure and lowest temperature. There were small differences between the Gulf Coast and Amarillo gases with respect to the magnitude of the partial derivatives at each pressure, temperature combination. Table 24 lists the maximum values of the partial derivatives over the entire 640 point space.

Table 24. Maximum values of the partial derivatives of the critical flow factor and density of natural gas with respect to mole fraction, pressure, and temperature

y	Units	$\frac{\partial C^*}{\partial y}$	$\frac{\partial \rho (lb/ft^3)}{\partial y}$
Nitrogen	mole %	-5.03×10^{-4}	1.357×10^{-2}
Methane	.	-1.12×10^{-3}	-4.49×10^{-2}
CO_2	.	5.025×10^{-4}	5.075×10^{-2}
Ethane	.	1.020×10^{-3}	3.265×10^{-2}
Propane	.	1.508×10^{-3}	6.382×10^{-2}
i-Butane	.	1.500×10^{-3}	9.350×10^{-2}
n-Butane	.	1.500×10^{-3}	9.500×10^{-2}
i-Pentane	.	2.000×10^{-3}	1.245×10^{-1}
n-Pentane	.	2.000×10^{-3}	1.275×10^{-1}
n-Hexane	.	2.000×10^{-3}	1.570×10^{-1}
P	psia	8.594×10^{-5}	4.063×10^{-3}
T	deg R	-4.55×10^{-4}	-8.91×10^{-3}

To complete the calculation of the uncertainties in the critical flow factor and the density, the random and systematic uncertainties in the mole fractions, pressure, and temperature are needed. The uncertainties in the pressure and temperature were considered previously. The uncertainties in the mole fractions are considered now. To compute the random uncertainties in the mole fractions, one must estimate the variance of the measured mole percent for each component. Since there were no repeated composition measurements during test runs because of the long turn-around time of the gas chromatograph, the data taken during tests on the chromatographic measurement system (sec. II.F) are taken as representative of the random uncertainty in composition measurement. Data for some repeated analyses of both gases that can be used for this purpose were given in table 15. The associated variances are given in table 25. A 99% confidence limit is taken to be 3 times the standard deviation (the square root of the variance). $s_{x_j r}$, the random uncertainty in the mole percent for the jth component, expressed in percent, is taken to be 100 times the standard deviation for that component divided by its concentration in mole percent.

Table 25. Repeated measured compositions of Gulf Coast gas taken from a sample bottle

Component	Variance
Nitrogen	6.942×10^{-5}
Methane	1.253×10^{-3}
CO_2	6.526×10^{-5}
Ethane	9.693×10^{-4}
Propane	9.137×10^{-6}
i-Butane	5.897×10^{-7}
n-Butane	2.940×10^{-6}
i-Pentane	2.701×10^{-6}
n-Pentane	9.517×10^{-7}
n-Hexane	2.593×10^{-8}

The systematic uncertainties in the composition variables are taken from the stated tolerances in the gravimetric manufacturing process of the standard gas samples given in table 26. The values differ between the two gases because the original specification was in parts per million, and the molecular weights of the two gases are different. Thus, conversion to a mole basis generates different values for the two gases. The molecular weight of the Gulf Coast gas was taken to be 16.865 and that of the Amarillo gas 17.629. Because the Amarillo gas values have the larger tolerances, they were used to compute the systematic error terms in the critical flow factor and density. The systematic relative uncertainties in percent of the component values, denoted by $s_{x_j s}$, are obtained from the stated tolerances by multiplying by 100 and dividing by the mole percent.

Table 26. Systematic errors in the two chromatograph gas standards

Component	Tolerances (mole %)	
	Gulf Coast	Amarillo
Nitrogen	0.00601	0.00628
Methane	0.05256	0.05494
CO2	0.00383	0.00400
Ethane	0.00561	0.00586
Propane	0.00382	0.00399
i-Butane	0.00058	0.00061
n-Butane	0.00058	0.00061
i-Pentane	0.00047	0.00049
n-Pentane	0.00047	0.00049
n-Hexane	0.00039	0.00041

Relative Uncertainty in the Mass Flow Rate of Natural Gas Through a Single Critical Nozzle

Combination of the appropriate systematic and random components yields the following expressions for the random and systematic relative uncertainties in percent in the mass flow rate through a single nozzle:

$$s_{\dot{m}_i r} = \left\{ \left[\left(3s_{Pf}\right)^2 + \left(3s_{Pm}\right)^2 \right] \text{x} \left[1 + \frac{P^2(8.594\text{x}10^{-5})^2}{C^{*2}} \right] + \left[\left(\frac{3}{2}\, s_{Tm}\right)^2 + \left(\frac{15}{2T}\right)^2 + \left(\frac{4.6}{2T}\right)^2 \right] \text{x} \left[1 + \frac{4T^2(4.55\text{x}10^{-4})^2}{C^{*2}} \right] + \left(3s_{C_d f}\right)^2 + 17\text{x}10^{-4} + \sum_j \left(3s_{x_j r}\, \frac{xj}{C^*}\, \frac{\partial C^*}{\partial x_j}\right)^2 \right\}^{1/2}$$

$$s_{\dot{m}_i s} = \left(98\text{x}10^{-4} + \frac{3.4}{P}\right) \text{x} \left(1 + \frac{P(8.594\text{x}10^{-5})}{C^*}\right) + \left(\frac{2}{2T}\right)\left(1 + \frac{2T(4.55\text{x}10^{-4})}{C^*}\right) + \sum_j \left|s_{x_j s}\right| \left|\frac{xj}{C^*}\,\frac{\partial C^*}{\partial x_j}\right| + 0.22 + 0.15 \cdot k + S_{NA} \text{ (syst. area term)},$$

where k = 1, nozzles throat diameter > 0.5328 inches, and
k = 0 otherwise.

The nozzle pressure P in this expression is in units of psia and the nozzle temperature T is in units of °R.

B. Relative Uncertainty in the Orifice and Meter Tube Diameter Values

The orifice and meter tube diameters contribute relatively small systematic components to the total uncertainty since the largest two of the orifice meters are used in this work and the capability to measure diameters is good. Both of these components are entirely systematic. The relative uncertainties in percent are

$$\begin{aligned} s_d &= 0.02/d \\ s_D &= 0.01/D \text{ for 6-inch meter tubes,} \\ s_D &= 0.02/D \text{ for 10-inch meter tubes,} \end{aligned} \tag{29}$$

where d and D are measured in inches.

C. Relative Uncertainty in Natural Gas Density at the Orifice Meter Due to Temperature and Pressure Uncertainty

The random and systematic error terms for density were developed in section IV.A. For orifice density, the expression contains the orifice pressure and temperature rather than the nozzle plenum pressure and temperature.

D. Uncertainty in the Differential Pressure

Equation (9) gave $s_{\Delta P}$, the relative uncertainty in percent in the differential pressure measurement at the orifice meter. The random and systematic uncertainties were given as

$$\begin{aligned} s_{\Delta Pr} &= 3\ (s_{\Delta Pf}^2 + s_{\Delta Pm}^2)^{1/2}, \text{ and} \\ s_{\Delta Ps} &= 0.018, \end{aligned} \tag{30}$$

where $s_{\Delta Pf}$ is the residual standard deviation of the fit to the differential pressures used in calibrating the transducer for the test run of interest, divided by the mean differential pressure, expressed in percent, and $s_{\Delta Pm}$ is the standard deviation of the mean differential pressure for the observations taken during the test run, divided by the mean differential pressure, expressed in percent.

E. Uncertainty in the Expansion Factor

The uncertainty in this factor is approximately 1 part in 100,000. It is neglected in calculating the uncertainty in the orifice discharge coefficient.

F. Uncertainty in Orifice Meter Discharge Coefficient

The expression for the total relative uncertainty in percent in the orifice discharge coefficient is the sum of the random, $s_{C_d r}$, and systematic, $s_{C_d s}$, uncertainty terms described in the previous paragraphs. One has

$$s_{C_d} = s_{C_d r} + s_{C_d s}$$

where

$$\begin{aligned}
s_{C_d r} = \Biggl\{ \sum_{i=1}^{n} \left(\frac{\dot{m}_i}{\dot{m}}\right)^2 \Biggl[& \left(\left(3 s_{P_n f}\right)^2 + \left(3 s_{P_n m}\right)^2\right) \times \left(1 + \frac{P_n^2 (8.594\text{x}10^{-5})^2}{C^{*2}}\right) \\
& + \left(\left(\frac{3}{2}\, s_{T_n m}\right)^2 + \left(\frac{15}{2T_n}\right)^2 + \left(\frac{4.6}{2T_n}\right)^2\right) \times \left(1 + \frac{4T_n^2 (4.55\text{x}10^{-4})^2}{C^{*2}}\right) \\
& + \left(3 s_{C_d f}\right)^2 + 17\text{x}10^{-4} + \sum_j \left(3 s_{x_j r} \frac{x_j}{C^*} \frac{\partial C^*}{\partial x_j}\right)^2 \Biggr] \\
& + \left(\left(3 s_{P_o f}\right)^2 + \left(3 s_{P_o m}\right)^2\right) \times \left(\frac{P_o \text{x}\ 4.063\text{x}10^{-3}}{2\rho_o}\right)^2 \\
& + \left(\left(3 s_{T_o m}\right)^2 + \left(\frac{15}{T_o}\right)^2 + \left(\frac{4.6}{T_o}\right)^2\right) \times \left(\frac{T_o \text{x}\ 8.91\text{x}10^{-3}}{2\rho_o}\right)^2 \\
& + \sum_j \left(\frac{1}{2}\, 3 s_{x_j r} \frac{x_j}{\rho} \frac{\partial \rho}{\partial x_j}\right)^2 + \left(\frac{3}{2}\, s_{\Delta P f}\right)^2 + \left(\frac{3}{2}\, s_{\Delta P m}\right)^2 \Biggr\}^{1/2}
\end{aligned}$$

$$s_{C_d s} = \sum_{i=1}^{n} \Bigg(\frac{\dot{m}_i}{\dot{m}} \Bigg(\Bigg(98\mathrm{x}10^{-4} + \frac{3.4}{P_n} \Bigg) \mathrm{x} \Bigg(1 + \frac{P_n (8.594\mathrm{x}10^{-5})}{C^*} \Bigg)$$

$$+ \Bigg(\frac{1}{1T_n} \Bigg) \Bigg(1 + \frac{2T_n \ (4.55\mathrm{x}10^{-4})}{C^*} \Bigg)$$

$$+ \Bigg(\sum_j |s_{x_j s}| \, \Bigg| \frac{x_j}{C^*} \frac{\partial C^*}{\partial x_j} \Bigg| \Bigg) + 0.22 + 0.15 \cdot k \Bigg) \Bigg) + \Bigg(\frac{2}{1-\beta^4} \Bigg) \Bigg(\beta^4 s_D + s_d \Bigg)$$

$$+ \Bigg(98\mathrm{x}10^{-4} + \frac{3.4}{P_o} \Bigg) \Bigg(\frac{P_o \ (4.063\mathrm{x}10^{-3})}{2\rho_o} \Bigg) + \Bigg(\frac{2}{T_o} \Bigg) \Bigg(1 + \frac{T_o \ (8.91\mathrm{x}10^{-3})}{2\rho_o} \Bigg)$$

$$+ \Bigg(\sum_j |s_{x_j s}| \, \Bigg| \frac{x_j}{\rho} \frac{\partial \rho}{\partial x_j} \Bigg| \Bigg) + \frac{0.018}{2} + S_{NA}$$

In this expression, subscript 'o' refers to orifice mean values, subscript 'f' refers to standard deviation of a fit, subscript 'm' refers to standard deviation of the mean of a population, and subscript 'n' refers to a mean value at the nozzle plenum. Summations on i refer to summing over the four nozzles, and summations on j refer to summing over the mole fractions of each of the components of the natural gas. Quantities pertaining to a given nozzle must be evaluated using the temperature, pressure, etc. pertaining to that nozzle. The units of pressure are psia, of temperature, °R, and of density, $\mathrm{lb/ft^3}$.

G. Example Calculation of Uncertainty Components for One Test Run

In order to illustrate the magnitudes and effects of uncertainties in the observed parameters, the following discussion addresses one test run's propagation of error analysis and gives the magnitudes of the parameters necessary to compute discharge coefficient values corresponding to each differential pressure value. Test number 150 taken on August 12, 1985 is used. The following tables give the pertinent test run identification information, the gas composition used in the calculation and the nozzle pressure and temperature observations. (150 observations of each were recorded.) The standard deviation of the mean pressures and temperatures and the residual standard deviation of the fits to pressure transducer calibration data are also listed. It should be noted that these are not multiplied by three to represent a 99% confidence interval. The remainder of this example calculation is performed using single standard deviation values. The final results may then be multiplied by three to obtain 99% confidence limits. For this test run three nozzles were used to obtain the desired flow rate through the orifice meter. The second nozzle manifold position is valved off as indicated below. Although the downstream block and bleed valve is test run three nozzles were used to obtain the desired flow rate through the orifice meter. The second nozzle manifold position is valved off as indicated below. Although the downstream block and bleed valve is closed for this nozzle, the pressure and temperature transducers were operative. The analysis program obtained mean and standard deviation values for these which were ignored in the remainder of the computation. The gas composition obtained from the chromatograph observation taken at approximately 7:55 a.m. is the most recent observation and is used for gas composition input data.

```
                 NGPL Orifice Test Point Number - 150
                  Date - 08/12/85    Time - 08:09:56
         Meter tube    - FE-9ABC   - diameter = 10.0829 inches
         Orifice plate - FE-9/0-4A - diameter =  5.7488 inches

           Chromatograph Data taken at 0755 hours on 08/12/85

    Component       Mole fraction    Component        Mole fraction

    Methane            89.860        I-Pentane             0.052
    Ethane              4.969        N-Pentane             0.041
    Propane             0.917        C6 Plus               0.042
    I-Butane            0.127        Nitrogen              3.301
    N-Butane            0.189        Carbon dioxide        0.501


          Nozzle Plenum Temperature and Pressure Observations

      Nozzle     -------  Pressure --------      --- Temperature ---
      Desig.     Plenum    S.D. Mean  Fit S.D.      Mean  S.D. Mean
                 (psia)    (psia)     (psia)        (°F)    (°F)

    1  1.0648    589.982     0.0077    0.361        70.62   0.0016
    2  OFF       589.809     0.0082    0.356        69.00   0.0065
    3  .7537     589.695     0.0083    0.425        70.60   0.0016
    4  1.3751    589.783     0.0081    0.299        70.19   0.0016


            Orifice Pressure and Temperature Observations
                              Mean     S.D. Mean  Fit S.D.
                             (psi)      (psi)     (psi)

            Diff. Pressure     3.8163    0.00069   0.0024
                               3.8156    0.00067   0.0014
            Static Pressure  588.539     0.010     0.2651

         Temperature = 70.69 °F, S. D. of the Mean = 0.0016 °F
```

1. Computation of Uncertainty in the Nozzle Mass Flow Rate

Computation of the various uncertainties contributing to the uncertainty in mass flow rate through the operating nozzle set is based on the observation of plenum temperature and pressure which propagate into the various parameter values necessary for computation of the nozzle mass flow rate. The following treats each contribution to the uncertainty in mass flow rate.

Pressure and Temperature Relative Uncertainty

The initial computation is that of the random and systematic components of the plenum pressures and temperatures. These are obtained from the forms of eq (22) for the pressure terms and eq (23) for the temperature terms. The equations are modified for this computation only, and we remove the factor of three associated with the 99% confidence limit. The values listed are given in relative terms in percent in keeping with the propagation of errors analysis. The random and systematic components of the uncertainties in pressure and temperature are listed below for the three operating nozzles. Nozzle designations correspond to the nozzle throat diameter in units of inches.

	Nozzle Desig.	Uncertainty Components			
		Pressure		Temperature	
		Random (%)	Syst. (%)	Random (%)	Syst. (%)
1	1.0648	0.0681	0.0152	0.0049	0.0019
3	0.7537	0.0722	0.0152	0.0049	0.0019
4	1.3751	0.0593	0.0152	0.0049	0.0019

Relative Uncertainty in the Critical Flow Factor for Natural Gas

Computation of the uncertainty components associated with the critical flow factor, C^*, using eq (25) and (26) yields the results given below. Three terms are involved which reflect the uncertainty due to pressure, temperature, and composition measurement. As discussed previously the gas composition term involves summations of random and systematic effects over all components. These involve the appropriate partial derivatives, variances, and tolerances, tabulated in tables 24, 25 and 26. The value of the square of the random composition term, the last term in eq (25), is $2.658 \times 10^{-5}/C^{*2}$. The value of the corresponding gas composition term for the systematic uncertainty component in the critical factor is $8.332 \times 10^{-3}/C^*$. The systematic term's value is obtained using the Amarillo Gas composition tolerances given in table 26 which gives the worst case estimate. The resulting uncertainty components for the critical flow factor in percent of the nozzle mass flow rate are listed below.

	Nozzle Desig.	C^*	Uncertainties	
			Random (%)	Syst. (%)
1	1.0648	0.69936	0.0095	0.0143
3	0.7537	0.69934	0.0097	0.0143
4	1.3751	0.69946	0.0092	0.0143

Uncertainty in the Nozzle Discharge Coefficient

Computation of the random component of the nozzle discharge coefficients combines the uncertainty in pressure and temperature measurements involved in nozzle calibration and the fitting uncertainty of the interpolating equation used in computing the nozzle discharge coefficient as shown in eq (24). The values for the random and components are given below in percent of the mass flow rate through the nozzle for one standard deviation in the random component. The systematic component reflects the use of the secondary system used in all of these nozzles' calibration.

	Nozzle Desig.	-- Nozzle Cd --	
		Random (%)	Syst. (%)
1	1.0648	0.0606	0.37
3	0.7537	0.0282	0.37
4	1.3751	0.0431	0.37

Uncertainty in the Nozzle Throat Area

As discussed previously the use conditions of the nozzle in natural gas flows were not the same as the calibration conditions. Computation of the relative uncertainty in the nozzle throat area uses the following average plenum and throat calibration temperatures for computation of the positive and negative bounds for this systematic effect.

Nozzle Average Calibration Temperatures

Nozzle	Plenum	Throat
0.09500	523.40	432.73
0.12500	531.73	439.90
0.18800	521.80	431.41
0.24960	525.14	434.06
0.37500	527.34	435.90
0.53280	519.69	429.59
0.75370	511.19	422.79
1.06480	507.67	420.13
1.37510	505.75	418.73
1.94500	487.83	403.68
2.33000	485.70	403.16

Computation of this systematic component requires the computation of the throat conditions for each nozzle. This is done using the equation of state calculation and the appropriate thermodynamic considerations. The pertinent temperatures for this test run are the following:

Plenum and Throat Temperatures and Pressures
for Test Run 150

Nozzle	-- Plenum --		-- Throat --		Temperature Diff.		Syst.
	Press. (psi)	Temp. (°R)	Press. (psi)	Temp. (°R)	Plenum (°R)	Throat (°R)	Unc. (%)
1.0648	589.98	530.29	320.80	456.08	22.62	35.95	0.058
0.7537	589.70	530.27	320.64	456.06	19.08	33.27	0.053
1.3751	589.78	529.86	320.69	455.69	24.11	36.96	0.059

The temperature differences between the calibration and run conditions are positive with the throat condition differences the largest. The systematic uncertainty in the mass flow rate due to differences in the calibration and use conditions and the associated effect on nozzle throat area are approximately 0.05 percent of the mass flow rate.

Mass Flow Rate Uncertainty for Individual Nozzles

Combinations of the various components contributing to the random and systematic mass flow rate uncertainties for each nozzle are tabulated below. Each of the component uncertainties is entered in relative terms as a percentage of the mass flow rate through the nozzle. The mass flow rate through each nozzle and its uncertainty in units of pounds per second are also listed.

Random Uncertainty Components

Nozzle	s_{Pr} (%)	s_{Tr} (%)	s_{C*r} (%)	$s_{C_d r}$ (%)	$\dot{m}_i$ (lb/sec)	$s_{\dot{m}_i r}$ (lb/sec)
1.0648	0.068	0.0049	0.0093	0.0606	9.660	0.0088
0.7537	0.072	0.0049	0.0097	0.0282	4.845	0.0038
1.3751	0.059	0.0049	0.0092	0.0431	16.085	0.1193
				Total	30.590	0.0153

Systematic Uncertainty Components

Nozzle	s_{Ps} (%)	s_{Ts} (%)	s_{C*s} (%)	$s_{C_d s}$ (%)	s_{area} (%)	$\dot{m}_i$ (lb/sec)	$s_{\dot{m}_i s}$ (lb/sec)
1.0648	0.0152	0.0019	0.0143	0.37	0.058	9.660	0.0444
0.7537	0.0152	0.0019	0.0143	0.37	0.053	4.845	0.0220
1.3751	0.0152	0.0019	0.0143	0.37	0.059	16.085	0.0741
					Total	30.590	0.1405

The relative random and systematic uncertainties in the mass flow rate through the measurement system are 0.005% and 0.459% respectively.

2. Computation of the Uncertainty in Orifice Parameters

Uncertainty of Computed Gas Density at the Orifice

Computation of the uncertainty in the orifice discharge coefficient due to random and systematic uncertainty components in the gas density may be calculated using eq (27) and (28). Both equations contain terms dependent upon the gas composition and are completely analogous with those discussed above for the nozzle critical flow factor. Evaluation of these two terms gives the following value for the square of the random gas composition term, 3.867×10^{-6}, and 0.003505 for the systematic term. Substitution of the appropriate parameter values with some rearrangement of terms in eq (27) and (28) gives the following expressions for the relative random and systematic uncertainties in the orifice density. The terms evaluated in table 24 for the partial derivatives of the density with respect to the temperature and pressure are used.

$$s_{\rho r} = \Big[[(0.265)^2 + (0.00069)^2] \times (1.651 \times 10^{-5}) + [(0.0016)^2 + (0.05)^2 + (.0153)^2] \times (7.939 \times 10^{-5}) + 3.867 \times 10^{-6} \Big]^{1/2} / [2(1.9999)].$$

$$s_{\rho s} = \Big[(588.543 \times 9.8 \times 10^{-5} + 0.034) \times 4.063 \times 10^{-3} + (0.02 \times 8.91 \times 10^{-3}) + .003505 \Big] / [2(1.9999)].$$

The relative random and systematic uncertainty components of the orifice discharge coefficient expressed in percent are obtained by multiplying each by 1/2 (see eq (21)) and by 100%. The values are

$$s_{\rho r} = 0.057\%, \quad s_{\rho s} = 0.101\%.$$

Uncertainty in the Observed Differential Pressure

The relative random and systematic uncertainty in the discharge coefficient due to uncertainty in the differential pressures may be computed using eq (30) and the partial derivative of the orifice discharge coefficient with respect to the differential pressure, which is 1/2. Substitution of the values of the standard deviation of the mean and the residual standard deviation of the fit to the calibration data gives the following values of the relative random and systematic uncertainties in the orifice discharge coefficient:

Mean	S.D. Mean	Fit S.D.	---- Unc. In C ---	---
			Random	Systematic
(psi)	(psi)	(psi)	(%)	(%)
3.8183	0.00069	0.0024	0.0327	0.009
3.8162	0.00067	0.0014	0.0204	0.009

Uncertainty due to Orifice and Meter Tube Diameter Measurement

Using eq (29) yields uncertainties in the orifice discharge coefficient due to uncertainty in plate and tube diameters of 0.008% due to plate diameter measurement and 0.0005% for meter tube diameter measurement. The magnitude of these errors is small relative to those from other parameters discussed above.

3. Computation of the Uncertainty in the Orifice Discharge Coefficient

The random uncertainty in the orifice discharge coefficient may be computed from the values obtained above. Although the final expression for uncertainty in C_d is quite complicated, it may be reduced to combination of three terms in quadrature, the random uncertainties in (1) the mass flow rate through the system, (2) the density of gas at the orifice conditions, and (3) the differential pressure, as follows for the two transducer observation sets:

$$s_{C_d r} = [(s_{\dot{m} r})^2 + (s_{\rho r})^2 + (s_{\Delta P r})^2]^{1/2}$$

$$s_{C_d r} = [(0.050)^2 + (0.057)^2 + (0.0327)^2]^{1/2} = 0.083\%$$

$$s_{C_d r} = [(0.050)^2 + (0.057)^2 + (0.0204)^2]^{1/2} = 0.079\%$$

These values represent a single standard deviation estimate of the random component. To obtain the 99 percent confidence interval in the estimate, these values should be multiplied by 3.

Similarly, the systematic uncertainty has two components of the same origin as those above, mass flow rate and differential pressure, in addition to the systematic effects of uncertainty in meter tube and orifice diameter measurement.

$$s_{C_d s} = s_{\dot{m} s} + s_{\rho s} + s_{P s} + s_D + s_d$$

$$s_{C_d s} = 0.459\% + 0.101\% + 0.008\% + 0.0005\% + 0.009\% = 0.577\%$$

The API has selected ANSI/ASME MFC-2M-1983, "Measurement Uncertainty for Fluid Flow in Closed Conduits", as a reference standard for calculating uncertainty of orifice flow discharge coefficients. However, in this report the authors have chosen the propagation of errors method (to estimate uncertainty in discharge coefficients) which differs from the API recommended procedure.

V. Data Acquisition and Control Systems

A. General Description

The data acquisition system used in this project consisted of an eight bit microprocessor interfaced to the various measurement instruments described in section II. The microprocessor system utilized the S-100 bus interface with 64 kilobytes of random access memory (64K RAM), a 20-megabyte hard disk, a single 8-inch floppy disk drive for data back-up, and a serial printer. The interfacing to the measurement system was accomplished using an IEEE-488 interface board and an RS-232C communications port.

The system software was developed using the BASIC and PASCAL programming languages for the data acquisition and run time results calculations. The database was constructed using a database manager having command interpretation capability. A word processor was used to maintain computerized notebooks of the operation of the measurement system and comments concerning operational errors or other notations by the operators during testing. Compiled BASIC was chosen because of the increased speed afforded both measurement and computational functions. The compiled PASCAL programs were used to perform computations of the preliminary results more quickly than could be done with BASIC programs. The database management software was used to maintain the database files generated by the system and to generate operator selection menus on the control console.

B. Data Acquisition System Hardware

The eight bit computer controlling the data acquisition and storage procedures utilized the S-100 interface bus and a Z-80A central processing unit (CPU) based microprocessor. Two interface boards were necessary for communication with the data acquisition system and hardware associated with the total system. A four port asynchronous communications controller provided four RS-232C serial communications channels. These were used for input/output operations to the console, printer, chromatograph, and modem. The second interface was one conforming to the IEEE-488 standard and used to communicate with the data acquisition/control system to the computer system. This interface functions as defined in the IEEE Standard 488-1975.

The data acquisition/control unit provided a front panel display and keyboard, a real-time clock and an HP-IB interface. It was configured with a 5 1/2 digit integrating voltmeter and current source. The digital voltmeter could resolve 1 microvolt signals and yielded excellent common and normal mode noise rejection. The assembly included a programmable current source which, when used with the digital voltmeter, could be used for high accuracy four terminal resistance measurements with 1 milliohm resolution. A twenty channel relay multiplexer was used to multiplex pressure and temperature signals to the digital voltmeter.

C. Data Acquisition System Software

The data acquisition system software controlled the two primary data acquisition procedures of the project, namely the pressure transducer calibration and orifice test run data acquisition. The software system was designed to be user-friendly and to involve as little operator involvement as practicable to minimize error in the database. The only data not automatically acquired by the computer were the ambient temperature for the static pressure transducer calibration and the barometric pressure. The entire system was menu-driven using the database management system's programming language capability for program control and data storage functions. The use of console screen menus was decided early in the planning of the project in order to minimize the possibility of operator error during data acquisition.

The software provided specific instructions displayed on the terminal to instruct the operator in the next step required by the current task at hand. Most inputs of a repetitive nature were put into look-up tables or files so that the operator need only choose a menu item or input an abbreviated response associated with the desired choice. However, a more important function of the software was the use of internal diagnostic procedures which, although transparent to the operator, continuously monitored the operational integrity of various components of the data acquisition system.

IEEE-488 Interface Bus Error Detection

Bus error detection for the IEEE-488 interface was used during all bus operations. The subroutine to check for errors was provided by the manufacturer and was used to check for the following errors:

1. Illegal function code
2. No listener
3. Service request
4. Timeout error
5. ATN true
6. IFC true
7. Reset S-100 system
8. Illegal error code.

During the entire phase of orifice meter testing, no such IEEE-488 bus errors occurred.

Pressure Transducer Calibration

During differential pressure transducer calibrations, a digital voltmeter was connected in parallel with the data acquisition input channel for the DDR-6000 differential pressure working standard to allow visual monitoring of the output voltage by the operator. This was used to set the pressure values prior to acquiring data for each calibration point. The voltages to be set were included in two files, one for the low range transducers and the other for the high range transducers. These data files were DPCAL20.TXT and DPCAL200.TXT, respectively. By using files in this way, the operator was prompted for the DDR-6000 voltage to set at each step of the calibration procedure. During the static pressure transducer calibration, the weight stack compositions placed on the deadweight testers were stored internally in the program as well as the mass values so that the pressure being applied was computed correctly. In this way data entry of the weight stack designations and mass values were preselected and not susceptible to operator error. The operator was instructed via a console display concerning which weights were to comprise the deadweight tester weight stack for each pressure value. From these internally stored values the pressures were computed with no opportunity for mistaken entry of the data into the databases.

The transducer calibration procedures were also designed so that the operator could either restart the current calibration or abort the entire set of three procedures at any point during the calibration when an error had been made. The appropriate entries to the system from the keyboard terminated the selected procedures, one or all three. This feature was included to minimize lost time because of possible operator error.

Before each pressure calibration procedure (low differential, high differential, or static) was completed, the transducer coefficients for the desired polynomial were computed as well as the standard deviation for the least squares fit. If the standard deviation was larger than the value prescribed in the operating procedures, the current calibration, e.g., low range differential transducers, could be rerun by the operator after entering the appropriate response. This feature was likewise designed to minimize lost time due to operator errors.

Orifice Plate Testing Checks and Diagnostics

More extensive built-in checks by the software system were used in the orifice data acquisition portion of the software. For example, all platinum resistance thermometer coefficients were stored in the program (NGPLTEST) so that a look-up table could link the temperature probes with their corresponding nozzle or orifice location. The static pressure transducer coefficients for the downstream nozzle locations were similarly stored in the program code. Furthermore, the pressure transducer calibration coefficients computed in the transducer calibration program, CAL488, were read by the data acquisition program so that no operator intervention was necessary to obtain the most current set of coefficient data.

The use of menus for operator input was extensive in the test run data acquisition program, NGPLTEST. The first menu allowed the selection of the meter tube to be tested. Depending on the choice of meter tube, the corresponding plate menu was next displayed for the operator. For both of these menus, the operator needed only to choose a number rather than to type a complete meter tube or plate designation. A separate routine in the software system allowed the operator to review these choices to reduce the possibility of an erroneous input. This software design enabled the operator to acquire data with minimal errors due to keyboard entry mistakes.

The next menu allowed for the selection of the nozzles in use. Again the operator chose a number corresponding to his choice. More than one of the nozzle manifold's four locations could be designated as "off", but the choice of the same nozzle more than once or of more than four nozzles generated an error message, after which the operator was asked to re-enter his selection. Prior to the 1985 data acquisition phase, a second nozzle manifold for the five smaller nozzles was added to the test loop. This manifold also had four nozzle holders. The software system allowed the operator to choose the proper nozzles as discussed above with the added constraint that no more than four nozzles could be in operation at one time, even though eight holders were available. This constraint was necessary to maintain compatibility with the database structure used for the 1984 data (see Appendix E for a summary of the database structures). The use of four of the nozzles allowed the operator sufficient latitude to select flow rates for the test runs. More nozzles were not needed for this purpose.

Immediately prior to orifice test run data acquisition, the test loop pressures and temperatures were displayed on the console display for the operator's benefit. It was necessary to allow the flow in the meter tube to stabilize before data acquisition could began. The software system also checked for various conditions in the test loop. For example, if a particular nozzle location was designated as "off", but a pressure ratio (upstream to downstream) greater than 1.05 existed, the computer displayed a warning to the operator that a leak might exist at that location. In addition, if a pressure ratio (nozzle plenum/nozzle downstream) less than 1.1 existed at a valid nozzle location, then the computer displayed a message for the operator that particular nozzle location appeared to be valved off. If the static pressure in the test loop fell below 480 psia, then the computer warned of dangerously low pressure to maintain choked flow in the nozzles. Finally, if the pressure fell below 460 psia, the program was aborted with the message that the static pressure was too low to continue. This particular data testing criterion also was useful in checking if the transducer coefficients had been read correctly or stored incorrectly in the file written by the earlier transducer calibration program.

During the acquisition of orifice data it was necessary to periodically obtain the current gas composition data from the chromatograph. The real-time clock in the data acquisition/control unit provided the means to coordinate the timing needed to prevent "locking out" the computer while the chromatograph was printing the gas composition information on paper tape. Because the chromatograph completed a gas analysis every 13 minutes, and because communications to the computer via the RS-232C interface were locked out during its output phase, it was necessary to allow chromatograph updates only during a prescribed time interval. Otherwise, the program would have to be restarted, and significant amounts of time could be lost as a result. The software system provided the necessary timing. If the data acquisition was delayed for whatever reason for more than 40 minutes since the last chromatograph update, the program automatically requested a new set of chromatograph data by suspending data acquisition operations until the current cycle of the chromatograph analysis was available for transfer to the computer.

Because the backing up of data on floppy diskettes used a data compression algorithm that required a significant amount of time, the software system also notified the operator when the current time was after 2:00 p.m. Central Standard Time. The operator could then obtain the final chromatograph analysis of the day prior to appending the orifice data to the database files. The files were then compressed prior to being copied onto floppy diskettes (two copies). This entire procedure required one to two hours to complete.

VI. Calibration and Test Procedures

The following sections present a detailed description of the procedures used during calibration of the pressure transducers and acquisition of orifice meter test data. As discussed in section V of this report, the data collection procedures were automated to the greatest extent possible consistent with realistic operation of the measurements systems. The initial objective of this approach was the reduction or elimination of human error in the recording of data. As the system was planned and constructed it became clear that the procedures necessary to collect the data could be made very uniform in their execution. To this end a menu driven software system was developed for the database collection activities. This approach utilized database management, word processing, and compiled BASIC and PASCAL software modules.

The detailed operating procedures provided by NBS personnel for use by NGPL personnel are given in Appendix H for both the calibration and orifice data acquisition portions of the overall software system. These detailed instructions are not discussed here but are left to the reader. The purpose of this section is to provide a description of the software system's operation.

The program and data files for all software systems used at NGPL utilized the B: drive of the hard disk, which was partitioned into three logical drives, A:, B:, and C:. The C: drive contained the database file structures, and the A: drive contained duplicate database files which could be sent to a remote facility by using the modem connected to one of the serial communications interfaces and the appropriate communications software. For data security reasons, the files located on drive A: were the only ones available via remote communications and were password protected. NBS Gaithersburg personnel had access to all files on the hard disk (drives A:, B:, and C:) via an unrestricted password.

A single main menu controlled all operator-selectable tasks. For the production of the database a relatively fixed sequence of operations was executed. The database was arranged generally in data blocks which contained all of the information developed during a single day. Each data block was begun with a full calibration of the pressure transducers, followed by orifice meter test run data. One of the constraints in the selection of the length of time allocated to the data blocks was the amount of data which could be stored on a one megabyte floppy diskette using the data compression algorithm format. A single orifice meter tube was tested during one data block with several data blocks necessary to complete the data for all orifice plates to be tested for that meter tube.

The main menu for the various tasks performed daily was written in the database manager command language. The menu as it appeared for the operators on the console screen, with the exclusion of phone numbers, is shown below:

```
                         NGPL ORIFICE TEST MENU

                 0 - EXIT
                 1 - Monitor test loop pressures and temperatures.
                 2 - Calibrate pressure transducers, compute
                     transducer coefficients, and append data
                     to appropriate databases.
                 3 - Obtain API orifice plate data, compute mean
                     pressures, temperatures, Re, and Cd, and
                     append data to appropriate databases.
>>>>>>>>>>>>>>>> 4 - THIS ITEM MUST BE DONE DAILY !!! <<<<<<<<<<<<<<<
                     Acquire end of day ENCAL reading, back up
                     all data on floppy diskette for shipment
                     to NBS Gaithersburg, initialize NGPL
                     database files, and put the terminal in
                     remote mode for data transmission.

 Phone numbers   - Bill Cleveland - (xxx) xxx-xxxx
                   Charlie Sindt  - (xxx) xxx-xxxx

 Enter desired option _
```

A. Pressure Transducer Calibration

Calibration of the pressure transducers was the first task performed each day. In order to begin the calibration, the operator would select item #2 of the main menu. The calibration task was accomplished using program CAL488, which controlled the calibration procedure itself and formed the database containing the observed and auxiliary parameter values. CAL488 also performed the least squares fitting procedures on the data for each transducer and produced the coefficient database for them. The basic features of this particular portion of the software system are shown in figure 8.

The order of the transducer calibrations was

1) 40-inch differential pressure transducers,
2) 250-inch differential pressure transducers, and
3) all static pressure transducers.

The only difference in the differential pressure transducer calibrations was the range of pressures to be covered. Otherwise, the software procedures were identical. This method was possible because of the use of two data files used as input to the calibration procedure, namely DPCAL20.TXT for the low pressure range and DPCAL200.TXT for the high range. (Examples of these menus were given in table 6 in Section II.D of this report.) These files contained the differential pressure working standard target voltage values to be set for the desired differential pressures. The use of external data files allowed the differential pressure values used for a calibration pass to be changed easily without changing the operating program in any way. After manual

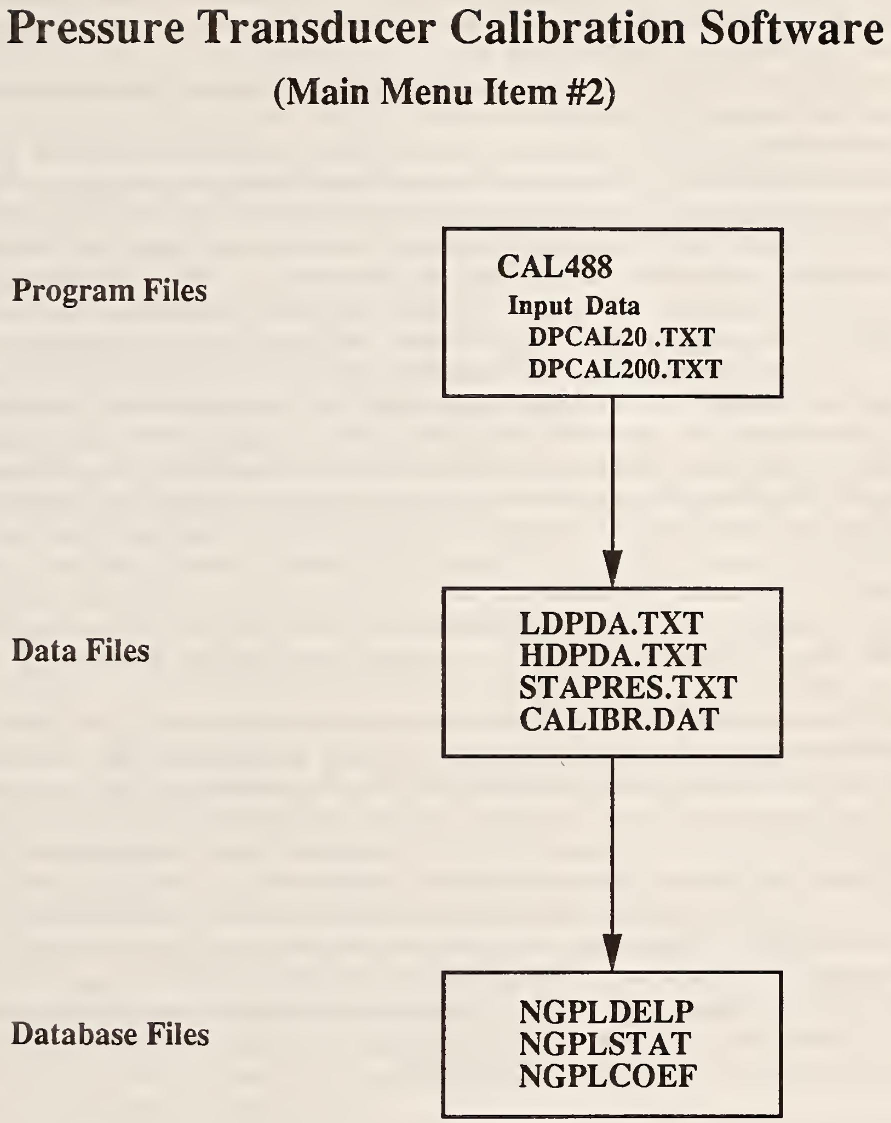

Pressure Transducer Calibration Software
(Main Menu Item #2)
Program Files
CAL488
Input Data
DPCAL20 .TXT
DPCAL200.TXT
Data Files
LDPDA.TXT
HDPDA.TXT
STAPRES.TXT
CALIBR.DAT
Database Files
NGPLDELP
NGPLSTAT
NGPLCOEF

Figure 8. Block diagram of transducer calibration software system.

entry of barometric pressure, the operator was instructed to perform the calibrations in a step-by-step fashion.

The differential pressure transducer calibration procedure was quite straightforward. After setting the static pressure of the transducers to a value near the current test loop static pressure, the operator was instructed by messages displayed on the computer's console to adjust the working standard voltage to the corresponding target voltage to obtain a particular differential pressure value. The initial observation was the zero differential pressure value. This value was necessary to obtain the working standard's response at zero differential pressure. Any character except a "4" was then entered to obtain five voltage measurements from the appropriate data acquisition system channels for each of the two transducers currently being calibrated and for the working standard. (Entering a "4" at this point allowed the operator to either restart the current calibration or abort the entire calibration program.) At the completion of the measurement cycle the mean values for the current data point were displayed for the operator. The operator could at this point accept the data point or enter a "0" to repeat the measurement. The date, time, transducer serial numbers, transducer mean voltages, and working standard mean voltage were stored in a data file called LDPDA.TXT for the low range transducers. Nine calibration data points over the range of 0 to 40 inches of water were used for these transducers. The same procedures were used for the 13-point calibration of the high range transducers over the range of 0 to 200 inches of water, and the data were stored in a data file called HDPDA.TXT.

The static pressure transducers were calibrated similarly. After the operator entered the temperature at the dead weight tester location and the barometric pressure, he was instructed by messages displayed on the console to place a series of weight stacks on the deadweight tester to generate a known static pressure. The computer then acquired five readings from the four static pressure transducers and averaged them. The restarting and program aborting procedures were identical to those for the differential pressure transducers discussed above. The calibration consisted of eight or nine pressure points in the range of 500 to 800 psia. The average transducer indications along with temperature, barometric pressure, weight stack designation, and other information were saved in a file called STAPRES.TXT.

The transducer calibration coefficients were computed following each portion of the calibration procedure. The low range differential pressure transducers were fit to a polynomial of previously determined degree using the least squares method. The operator was instructed to repeat the calibration if the standard deviation computed by the fitting routine exceeded 0.001 psid. A third order fit of the data was used for the high range differential pressure transducers. If the standard deviation for these transducers exceeded 0.01 psid, then the operator was instructed to repeat the calibration. A second order fit was used for the four static pressure transducers. The standard deviation maximum for these transducers was 0.6 psia. These calibration coefficients were stored in the data file CALIBR.DAT.

Upon completion of all pressure transducer calibration procedures, the data files LDPDA.TXT and HDPDA.TXT were appended to database file NGPLDELP.DBF, the data file STAPRES.TXT was appended to NGPLSTAT.DBF, and the data file CALIBR.DAT was appended to database file NGPLCOEF.DBF as shown in figure 8. The software system then returned to the main menu.

B. Orifice Meter Data Acquisition Procedures

Figure 9 shows a block diagram illustrating the logical basis for the software system used to acquire the flow measurement system data during orifice discharge coefficient measurement operations. Data acquisition during orifice meter testing was accomplished using three programs, NGPL, RENCAL, and NGPLTEST. Using the BASIC "CHAIN" statement, these three programs were chained together due to memory size limitations of the computer system. The "%INCLUDE" compiler directive was used along with the file COMDEF.BAS in order to declare common variables, functions, and subroutines used by each of the programs. Data acquisition was started by choosing item #3 in the main menu. This choice loaded and ran the first of the three chained programs. It should be stressed that the loading of these programs from the systems disk was transparent to the operator, whose menu selections controlled operations at any time.

NGPL is an initialization program. Its tasks were to initialize variables and place two zeroes in the data file NUMBFILE.DAT. The data acquisition software next chained to the program RENCAL (repeated gas analysis). This program acquired gas composition information from the chromatograph. It was necessary for the operator to be certain that the chromatograph was not about to print its previous analysis prior to beginning orifice data acquisition so that the computer would not become "locked out", as described in section V. This event was possible only at the time when item #3 of the main menu was chosen, since the software system controlled the timing after the start of data acquisition operations. The date, time, analysis time, and gas composition were stored in data files GCDATA*.DAT. The * indicates ascending numbers from one up to the number of times the measurement was performed during testing. After the ENCAL analysis was displayed on the screen, the system paused until the operator pressed the space bar to continue data acquisition by chaining to NGPLTEST.

NGPLTEST was the final of the three chained programs and acquired the orifice discharge coefficient data over the desired flow rate range. This program first read the contents of the data file NUMBFILE.DAT, which contained the number of chromatograph analysis files and the number of orifice test point files that were currently saved on the hard disk. The program then recalled the previous meter tube, orifice plate, run number, barometric pressure, and nozzle designations from the file NGPLSTAT.DOC. After the program displayed the transducer calibration date, the operator entered the barometric pressure and then was presented two menus, one for the meter tube designation and the other for the orifice plate designation. A carriage return for either menu retained the designations read from the file NGPLSTAT.DOC. Otherwise, the designations were chosen with a number that corresponded to the

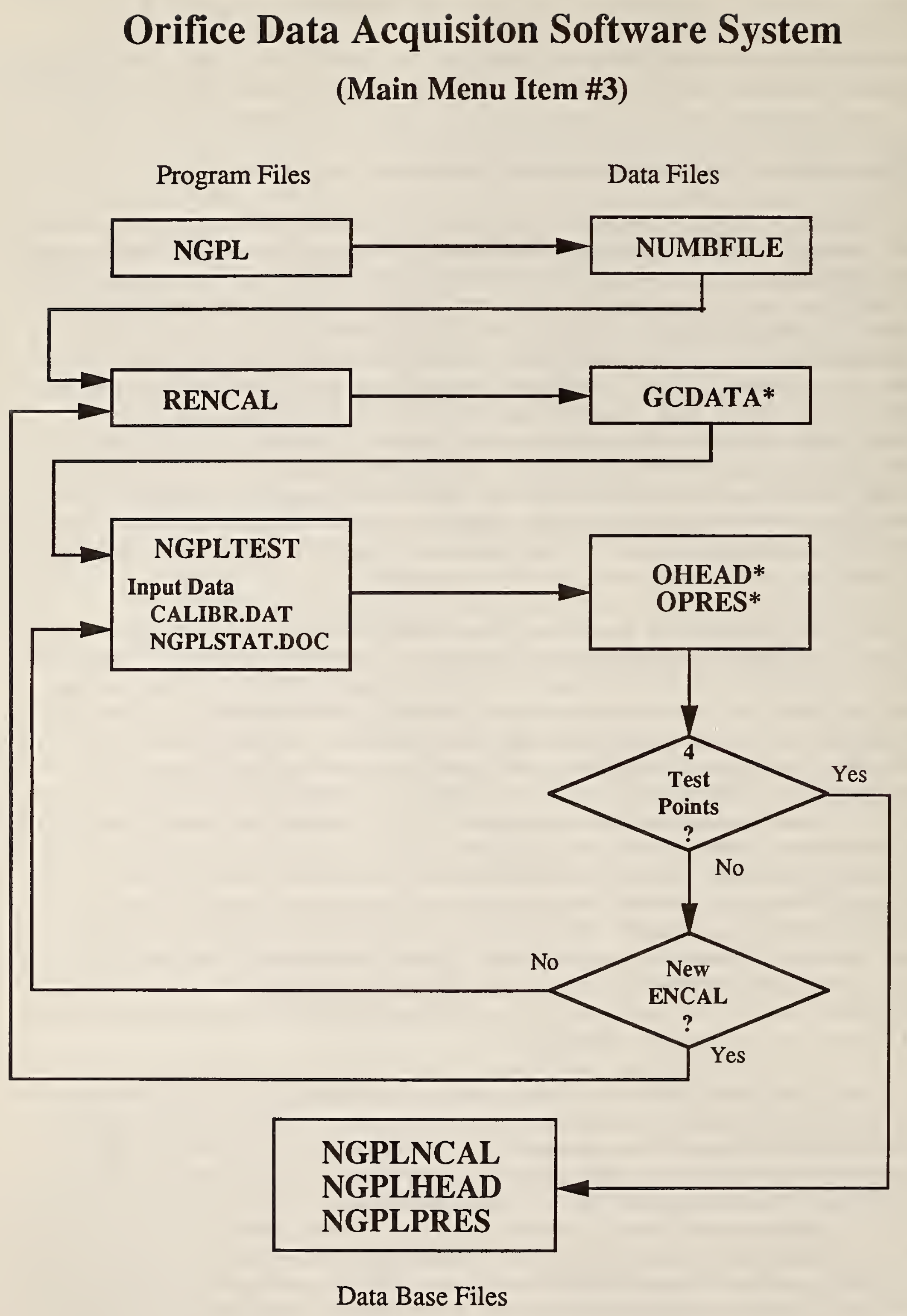

Orifice Data Acquisiton Software System
(Main Menu Item #3)
Program Files
Data Files
NGPL
NUMBFILE
RENCAL
GCDATA*
NGPLTEST
Input Data
CALIBR.DAT
NGPLSTAT.DOC
OHEAD*
OPRES*
4
Test
Points
?
Yes
No
No
New
ENCAL
?
Yes
NGPLNCAL
NGPLHEAD
NGPLPRES
Data Base Files

Figure 9. Data acquisition software block diagram

meter tube or orifice plate desired. After the operator made a selection, the software system allowed him to review his entries before they were finally stored in computer memory.

The next portion of NGPLTEST presented the operator with two nozzle menus, the first for the large manifold and the second for the small manifold (for 1985 operations). Again the operator was to choose a number corresponding to the nozzle installed at each location and his entries could be reviewed prior to final storage in memory. The number "12" was chosen for a location that was unused, or "off". As discussed in section V, the software system checked the choices made by the operator for duplication of nozzles and for too many nozzles. It should be stressed at this point that NGPL operating personnel were responsible for the correct input of the nozzle designations and that if a mistake was made at this point, there was no means to identify, or to later recover from, the error. The resulting computed mass flow rate would be in error, and the computed discharge coefficient likewise would be in error.

The operator was next instructed to enter any comments he might have concerning weather conditions or anything felt to be out of the ordinary or worthy of saving in the notebook file. In this way the run time information by the operators could be kept to help identify errors in the data collection procedures, e.g., valves were not closed when they should have been, etc.

The program then entered a scan mode so that the operator could monitor temperature and pressure conditions in the test loop for stability. This section of the program displayed the 10 most current values of the orifice static and differential pressures and of the orifice and nozzle temperatures. This monitor program could be run at any time from the main menu by choosing item #1 from the menu. The particular program used for menu item #1 was called SCAN. Not only did this program display the temperatures and pressures as described above, but also the operator could choose to display the orifice static pressure, the differential pressure values of each of the four transducers, and the differential working standard's voltage.

As discussed in section V, the monitor section of NGPLTEST also checked for a pressure drop across a nozzle location designated as off and monitored the static pressure in the loop so that operation could not continue if the pressure fell below 460 psia. The operator used this monitoring function to determine when stable and acceptable conditions in the flow system were reached. Data acquisition were then initiated by pressing the space bar on the console. Data acquisition required approximately 6 minutes for a single test point and, generally, four test points were taken at a single flow rate. Each orifice plate was tested at 4 or 5 differential pressures up to the maximum allowed by the currently installed, high range differential pressure transducers at the existing line pressure in the test loop. (These differential pressures were selected to yield approximately equal incremental changes in the Reynolds number over the flow rate range.) During the time of orifice data acquisition, the data acquisition system read the values from each of the pressure transducer and PRT elements sequentially 150 times.

Each of the 150 voltage values read from the data acquisition/control unit were stored. Data files OHEAD*.DAT and OPRES*.DAT were used to store the raw data. Again the * indicates ascending numbers from one up to the number of times the measurement was performed. The final number was saved in the file NUMBFILE.DAT to aid in appending of orifice data to the database files NGPLHEAD.DBF and NGPLPRES.DBF.

After a single test point was measured, the software system chained back to RENCAL in order to obtain new gas composition data if the clock indicated that a new analysis was available. If not, the system continued with the next test point. The software system continued in a cyclic manner between RENCAL and NGPLTEST until a single flow rate observation sequence was completed. Then the system ran a program called NGPLCNVT, which converted data files to a form suitable for input to the program NGPLAVGP that computed mean pressures, temperatures, mass flow rate, and discharge coefficient. This program was written in the PASCAL language to attain the smallest computational time. Finally, the data were appended to the appropriate database files as described above, and another ENCAL analysis was obtained using program ENCAL.

After the database files had been appended, the software system called the word processor to append the file COMMENT.DOC to a list of notes kept during the course of the project called NOTEBOOK.DOC. This file contained not only comments from the operator as described above, but also such data as the date, time, and plate and meter tube designations. This notebook was an extremely useful tool for the operators as well as the managers of this program in recording the events occurring during the tests.

After six flow rate observation sequences, or 24 test points, or at the end of the day, it was necessary for the operator to obtain one final gas analysis and back up all files on two floppy diskettes using item #4 of the main menu. This portion of the software system ran a program called FENCAL (final gas analysis) and then used a data compression algorithm to reduce the size of the data files in order to allow more data to be stored on a floppy diskette. After the two floppies were created, one was mailed to NBS-Gaithersburg for analysis, and the other was kept as a back-up at NGPL. Finally, the software system initialized all of the necessary files and stopped so that the operator could turn off the system until the next day.

VII. Operating Procedures, Test Run Inventory, Test Run Data Analysis Results, and Analysis of the Results

The extent of the complete database generated during the course of this work is quite large. It is stored in computer readable form only and available from either NBS or API. The bulk of the database consists of the 150 sets of differential pressure, static pressure, and temperature transducer observations recorded for each test run. The results of the analyses of the final database are much less extensive. However, listing of all the intermediate parameter values for each test run is not possible here. To keep the size of this report within manageable proportions, the results for each valid test run are summarized in a single line of information. Plots of discharge coefficient vs. pipe Reynolds number are also given for each orifice meter. A brief discussion is given of the operational events and the data collection procedures used in collection of the final database since these effect the test run analysis.

Analysis of the database was done with software having numerical precision of 12 digits. This was compared with codes of known numerical accuracy of 8 digits and found to agree at the 8 digit level.

The final database contains the normal operational malfunctions and blunders encountered in obtaining any experimental database. A detailed inventory of the test runs which identifies those runs for which malfunctions occurred and were identified as such is included.

A. Operating Schedule, Final Database Definition, and Archiving of the Database

A detailed operational history of this project from its inception through its completion is given in Appendix B of this report. It is chronological and is largely drawn from the progress reports submitted to the API over the course of the data collection period. A brief description of the major events shaping the structure and segmentation of the database is given here to provide the rationale for elimination of certain blocks of test runs from the analysis procedures discussed here.

General Operating Schedules and Database Segments

As mentioned previously the governing consideration of the time periods for the tests was the outside temperature at the test site. In an attempt to insure that the natural gas temperature in the critical nozzle throats was above the hydrocarbon dew point, the testing schedule was conducted during the summer and fall of the year. Identification of test runs was chronological beginning with test run number 1 for both years in which data collection was done. Test run numbers were sequential for each year with the exception of beginning test runs in 1985 which were numbered 971 through 974 taken on July 25, 1985.

The four largest meter tubes were tested over the two year period of the project. The FE-7ABC meter tube was tested in both years. The original plan for the project was to complete the tests in one year, and to test a single meter tube of each size, i.e., 6- and 10-inch. However, after completion of the 1984 testing schedule, the effects of variation in the surface roughness were demonstrated in the intermediate Reynolds number project [1] in the winter and spring of 1985. The API's Orifice Meter Database Steering Committee decided to repeat the tests in natural gas in the summer of 1985 with the newly refurbished meter tubes which had not been subjected to water flows and their attendant corrosive effects. In addition it was decided to test one of the 6-inch meters after it had been electroless nickel plated to determine whether any effects of the nickel plating could be detected in natural gas flows. (All of the meter runs were electroless nickel plated for corrosion resistance purposes in the intermediate Reynolds number project [1].)

The database in 1984 is divided by events into two segments. The first segment contains test runs number 1 through 403. These test runs were taken with the original differential pressure transducers. As described in Appendix B the high range set of these transducers was found to exhibit unacceptably large drifts of the zero differential pressure response and was replaced. The remainder of the test runs collected in 1984 were number 501 and higher and used the replacement high range differential pressure transducers. Test runs in the first segment taken at differential pressures below 40 inches of water are considered to be valid and are included in the final database. All of the test runs of the second segment of the 1984 test run data are included except for those indicated by the operators as being in error for a variety of operational difficulties. These difficulties are noted in the inventory.

The 1985 database is a single segment. All test run data except those indicated by the operators as having operational difficulties are included in the final database.

The typical daily operating schedule consisted of

(1) calibration of all absolute and differential pressure transducers,
(2) computation of calibration coefficients for each transducer,
(3) test run data collection and analysis procedures, and
(4) data compression and storage.

Flow set points were generally selected to span the Reynolds number range possible for each orifice meter in approximately equal increments. However, this was not always realized due to changing pipeline pressure and the finite number of nozzles as flow standards.

Test series (a set of consecutive test runs for a particular Reynolds number range) were replicated at least once except in the latter portions of the testing seasons when replications were not possible due to the weather. Generally, this was done on a different day. In many cases the orifice plate was removed from the meter tube between replications.

B. Inventory of the Final Database

The final database consists of the two 1984 segments and the 1985 segment. The inventory of the final database is given in table 27, and is arranged by meter tube and orifice plate. Each section of the inventory table has a listing of the test run blocks analyzed and those marked for deletion. The causes for deletion are given in the comments column. Several causes were recurrent throughout the testing. These have been assigned a character code which is given in the comments column. These codes are listed below. Otherwise, specific causes are cited for the deletion. Those test runs marked for deletion were so marked as a result of operator observations of malfunction in the measurement, orifice meter or pipeline systems. No other basis was used for identification of a test run as deleted with one exception. Test runs taken in the early portion of 1984, through August 20 (1-403), were taken with high range differential pressure transducers which showed considerable zero drift. Test runs taken during this period having a differential pressure value greater than 40 inches of water are eliminated from the list of acceptable runs. These test runs are listed in the deleted run section of the inventory, but are contained in the archival data files. These test runs were only deleted from the analysis and were not physically deleted from the database. All runs recorded are archived. Some runs were interrupted before the observed data were recorded by the data acquisition system. These were never available and are not contained in the archival record of the database.

Deletion Comment Codes

# - Keyboard entry error. Improper responses were given by the operator to the data acquisition microprocessor.

+ - Run numbering skip.

* - Operator Indicated Deletion, no specific notation as to cause.

! - Test runs taken in early 1984 having differential pressures above 40 in. of water.

The inventory constitutes a list of acceptable and unacceptable test runs. As mentioned above the criteria used for labelling test runs as unacceptable are based solely on the identification of operational difficulties at the time of the test or because segments of test runs were recorded for diagnostic purposes.

Table 27. Inventory of observation runs.

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Total Runs
09/10/84	FE-7ABC	FE-7/8-1B	501	504	4	
09/11/84	FE-7ABC	FE-7/8-1B	505	512	8	
09/12/84	FE-7ABC	FE-7/8-1B	513	520	8	
09/23/85	FE-7ABC	FE-7/8-1B	397	412	16	
10/07/85	FE-7ABC	FE-7/8-1B	513	528	16	
10/31/85	FE-7ABC	FE-7/8-1B	700	719	20	72
08/15/84	FE-7ABC	FE-7/8-2A	344	355	12	
09/20/84	FE-7ABC	FE-7/8-2A	586	597	12	
09/21/84	FE-7ABC	FE-7/8-2A	598	609	12	36
08/16/84	FE-7ABC	FE-7/8-2B	374	379	6	
08/20/84	FE-7ABC	FE-7/8-2B	380	391	12	
09/24/85	FE-7ABC	FE-7/8-2B	413	420	8	
09/27/85	FE-7ABC	FE-7/8-2B	460	483	20	
10/30/85	FE-7ABC	FE-7/8-2B	678	699	20	66
08/07/84	FE-7ABC	FE-7/8-3A	236	259	24	
08/10/84	FE-7ABC	FE-7/8-3A	308	319	12	
09/30/85	FE-7ABC	FE-7/8-3A	484	504	19	
10/01/85	FE-7ABC	FE-7/8-3A	505	508	4	
10/29/85	FE-7ABC	FE-7/8-3A	658	677	20	79
08/13/84	FE-7ABC	FE-7/8-3B	332	337	6	
09/24/84	FE-7ABC	FE-7/8-3B	610	629	20	26
08/03/84	FE-7ABC	FE-7/8-4A	176	187	12	
08/13/84	FE-7ABC	FE-7/8-4A	338	343	6	
09/26/84	FE-7ABC	FE-7/8-4A	630	651	20	38
08/06/84	FE-7ABC	FE-7/8-4B	206	217	12	
10/01/85	FE-7ABC	FE-7/8-4B	509	512	4	
10/25/85	FE-7ABC	FE-7/8-4B	638	657	20	36

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Total Runs
07/09/84	FE-7ABC	FE-7/8-5A	37	45	8	
07/13/84	FE-7ABC	FE-7/8-5A	46	51	6	
07/18/84	FE-7ABC	FE-7/8-5A	65	70	6	
07/23/84	FE-7ABC	FE-7/8-5A	85	96	12	
07/25/84	FE-7ABC	FE-7/8-5A	98	109	12	
09/28/84	FE-7ABC	FE-7/8-5A	672	691	20	64
07/26/84	FE-7ABC	FE-7/8-5B	110	121	12	
10/24/85	FE-7ABC	FE-7/8-5B	618	637	20	32
07/03/84	FE-7ABC	FE-7/8-6A	1	6	6	
07/05/84	FE-7ABC	FE-7/8-6A	7	12	6	
10/01/84	FE-7ABC	FE-7/8-6A	692	703	12	
10/03/84	FE-7ABC	FE-7/8-6A	704	711	8	
10/22/85	FE-7ABC	FE-7/8-6A	606	617	12	44
07/31/84	FE-7ABC	FE-7/8-6B	140	151	12	
10/08/85	FE-7ABC	FE-7/8-6B	529	536	8	
10/10/85	FE-7ABC	FE-7/8-6B	537	540	4	
10/21/85	FE-7ABC	FE-7/8-6B	598	605	8	32
09/14/84	FE-7ABC	FE-7/8-7A	541	560	20	20
09/17/84	FE-7ABC	FE-7/8-7B	561	572	12	
09/18/84	FE-7ABC	FE-7/8-7B	573	578	6	
09/16/85	FE-7ABC	FE-7/8-7B	373	380	8	
09/17/85	FE-7ABC	FE-7/8-7B	381	388	8	34
09/12/84	FE-7ABC	FE-7/8-8A	521	528	8	
09/13/84	FE-7ABC	FE-7/8-8A	529	540	12	20
11/01/85	FE-7ABC	FE-7/8-8B	720	739	20	20
					Total Test Runs	619

Table 27. Inventory of observation runs -- Continued

			Deleted Runs			
Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Comments
09/18/85	FE-7ABC	FE-7/8-1B	389	396	8	data recording error - #2 nozzle static pressure low (332 psig), data channel voltage values all low relative to the other operating nozzles
10/15/85	FE-7ABC	FE-7/8-1B	541	556	16	CEESI/NBS investigation
10/16/85	FE-7ABC	FE-7/8-1B	557	562	6	of data acquisition &
10/17/85	FE-7ABC	FE-7/8-1B	563	568	6	instrumentation syst.
08/15/84	FE-7ABC	FE-7/8-2A	356	367	12	*
09/20/84	FE-7ABC	FE-7/8-2A	581	584	4	temperature data recording error
09/20/84	FE-7ABC	FE-7/8-2A	585	585	1	operating program abort
08/15/84	FE-7ABC	FE-7/8-2B	368	373	6	*
08/20/84	FE-7ABC	FE-7/8-2B	392	403	12	*
09/25/85	FE-7ABC	FE-7/8-2B	429	431	3	system error
09/25/85	FE-7ABC	FE-7/8-2B	421	435	15	CEESI monitored diagnostic tests
09/26/85	FE-7ABC	FE-7/8-2B	440	459	20	CEESI monitored diagnostic tests
09/27/85	FE-7ABC	FE-7/8-2B	464	467	4	thermometer connected incorrectly
10/30/85	FE-7ABC	FE-7/8-2B	687	687	1	system error
10/30/85	FE-7ABC	FE-7/8-2B	691	691	1	system error
08/07/84	FE-7ABC	FE-7/8-3A	260	271	12	*
08/08/84	FE-7ABC	FE-7/8-3A	272	295	24	*
08/09/84	FE-7ABC	FE-7/8-3A	296	307	12	*
08/10/84	FE-7ABC	FE-7/8-3A	320	331	12	*
09/30/85	FE-7ABC	FE-7/8-3A	487	487	1	system error
09/30/85	FE-7ABC	FE-7/8-3A	496	496	1	system error

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Deleted Runs Run No.		Num. of Runs	Comments
			Beg.	End		
08/03/84	FE-7ABC	FE-7/8-4A	170	175	6	nozzle 2 static pressure data input channel error, pressure value 80 psi below other nozzle plenum pressures
08/03/84	FE-7ABC	FE-7/8-4A	188	205	18	*
09/26/84	FE-7ABC	FE-7/8-4A	642	643	2	power failure at the test site
08/06/84	FE-7ABC	FE-7/8-4B	218	235	18	*
07/13/84	FE-7ABC	FE-7/8-5A	52	57	6	*
07/15/84	FE-7ABC	FE-7/8-5A	58	64	7	+
07/19/84	FE-7ABC	FE-7/8-5A	71	76	6	*
07/20/84	FE-7ABC	FE-7/8-5A	77	84	7	*
07/25/84	FE-7ABC	FE-7/8-5A	97	97	1	+
09/27/84	FE-7ABC	FE-7/8-5A	652	671	20	operator indicates bad orifice pressure readings
07/26/84	FE-7ABC	FE-7/8-5B	122	127	6	*
07/27/84	FE-7ABC	FE-7/8-5B	128	139	12	*
07/05/84	FE-7ABC	FE-7/8-6A	13	18	6	*
07/06/84	FE-7ABC	FE-7/8-6A	19	36	18	*
07/31/84	FE-7ABC	FE-7/8-6B	152	169	18	*
10/17/85	FE-7ABC	FE-7/8-6B	569	574	6	CEESI/NBS investigation of data acquisition instrumentation
10/18/85	FE-7ABC	FE-7/8-6B	575	593	19	
10/21/85	FE-7ABC	FE-7/8-6B	594	597	4	incorrect nozzle designation entry
10/18/85	FE-7ABC	FE-7/8-6B	583	585	3	chromatograph timing cycle exceeded
09/25/85	FE-7ABC	FE-7/8-7B	436	439	4	CEESI monitored diagnostic tests
09/18/84	FE-7ABC	FE-7/8-7B	579	580	2	temperature data recording error

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Total Runs
11/18/85	PE-8ABC	FE-7/8-1B	864	884	20	20
11/12/85	PE-8ABC	FE-7/8-2B	822	845	24	
11/15/85	PE-8ABC	FE-7/8-2B	848	863	16	40
11/11/85	PE-8ABC	FE-7/8-3A	802	821	20	
11/21/85	PE-8ABC	FE-7/8-3A	913	932	20	40
11/07/85	PE-8ABC	FE-7/8-4B	780	801	21	21
11/05/85	PE-8ABC	FE-7/8-5B	740	759	20	20
11/06/85	PE-8ABC	FE-7/8-6B	760	779	20	20
11/19/85	PE-8ABC	FE-7/8-8B	889	908	20	20
					Total Test Runs	181

Deleted Runs

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Comments
11/18/85	PE-8ABC	FE-7/8-1B	872	872	1	chromatograph timing cycle exceeded
11/15/85	PE-8ABC	FE-7/8-2B	846	847	2	chromatograph timing cycle exceeded
11/21/85	PE-8ABC	FE-7/8-3A	909	912	4	valve partially closed during plate change
11/07/85	PE-8ABC	FE-7/8-4B	785	785	1	system error
11/19/85	PE-8ABC	FE-7/8-8B	885	888	4	operator indicates a small leak around an indicating gauge stem

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Total Runs
08/21/85	FE-9ABC	FE-9/0-1B	230	247	16	
08/22/85	FE-9ABC	FE-9/0-1B	248	258	10	
08/23/85	FE-9ABC	FE-9/0-1B	260	267	8	
08/26/85	FE-9ABC	FE-9/0-1B	270	277	8	
08/27/85	FE-9ABC	FE-9/0-1B	279	282	4	46
08/08/85	FE-9ABC	FE-9/0-2A	114	125	12	
08/09/85	FE-9ABC	FE-9/0-2A	126	137	12	
09/04/85	FE-9ABC	FE-9/0-2A	357	372	16	40
08/02/85	FE-9ABC	FE-9/0-2B	34	57	24	24
07/30/85	FE-9ABC	FE-9/0-3B	1	8	8	
07/31/85	FE-9ABC	FE-9/0-3B	9	25	16	
08/01/85	FE-9ABC	FE-9/0-3B	26	33	8	
08/30/85	FE-9ABC	FE-9/0-3B	330	345	15	
09/03/85	FE-9ABC	FE-9/0-3B	346	356	8	55
08/09/85	FE-9ABC	FE-9/0-4A	138	149	12	
08/12/85	FE-9ABC	FE-9/0-4A	150	153	4	
08/14/85	FE-9ABC	FE-9/0-4A	182	193	12	28
08/05/85	FE-9ABC	FE-9/0-4B	58	73	12	
08/14/85	FE-9ABC	FE-9/0-4B	194	201	8	20
08/06/85	FE-9ABC	FE-9/0-5B	74	85	12	
08/15/85	FE-9ABC	FE-9/0-5B	202	213	12	24
08/12/85	FE-9ABC	FE-9/0-6A	154	161	8	
08/13/85	FE-9ABC	FE-9/0-6A	162	173	8	
08/19/85	FE-9ABC	FE-9/0-6A	222	229	8	24
08/08/85	FE-9ABC	FE-9/0-6B	102	113	8	
08/13/85	FE-9ABC	FE-9/0-6B	174	181	8	
08/19/85	FE-9ABC	FE-9/0-6B	214	221	7	23
08/27/85	FE-9ABC	FE-9/0-7B	283	286	4	
08/29/85	FE-9ABC	FE-9/0-7B	310	325	16	
08/30/85	FE-9ABC	FE-9/0-7B	326	329	4	24

Total Test Runs 308

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Deleted Runs Run No. Beg.	End	Num. of Runs	Comments
08/21/85	FE-9ABC	FE-9/0-1B	242	243	2	data lost due to conflict with chromatograph print cycle
08/22/85	FE-9ABC	FE-9/0-1B	254	254	1	data lost due to conflict with chromatograph operating cycle
08/22/85	FE-9ABC	FE-9/0-1B	259	259	1	operator abort - incorrect PRT connection
08/26/85	FE-9ABC	FE-9/0-1B	268	269	2	error in recording transducer coeff. file
08/27/85	FE-9ABC	FE-9/0-1B	278	278	1	system error
07/31/85	FE-9ABC	FE-9/0-3B	21	21	1	system error
08/30/85	FE-9ABC	FE-9/0-3B	335	335	1	chromatograph timing cycle exceeded
09/03/85	FE-9ABC	FE-9/0-3B	350	352	3	system error
07/25/85	FE-9ABC	FE-9/0-3B	971	974	4	initial four system test done at the beginning of the 1985 data collection period. Run numbers set to 971 - 974 in anticipation of not using them in normal test runs.
08/05/85	FE-9ABC	FE-9/0-4B	62	65	4	pressure transducer not properly zeroed.
08/13/85	FE-9ABC	FE-9/0-6A	166	169	4	incorrect nozzle desig. entered

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Deleted Runs Run No. Beg.	End	Num. of Runs	Comments
08/06/85	FE-9ABC	FE-9/0-6B	86	93	8	orifice plate not concentric with the meter tube
08/07/85	FE-9ABC	FE-9/0-6B	94	101	8	orifice plate not concentric with the meter tube
08/08/85	FE-9ABC	FE-9/0-6B	106	109	4	valve on #1 up stream pressure transducer closed
08/19/85	FE-9ABC	FE-9/0-6B	217	217	1	low orifice static pressure
08/28/85	FE-9ABC	FE-9/0-7B	299	299	1	nozzle desig. error
08/29/85	FE-9ABC	FE-9/0-7B	308	309	2	system error
08/28/85	FE-9ABC	FE-9/0-7B	287	307	21	FE-9/0-5A orifice plate installed upstream of the meter run

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Run No. Beg.	Run No. End	Num. of Runs	Total Runs
11/07/84	FE-0ABC	FE-9/0-1A	915	922	8	
11/15/84	FE-0ABC	FE-9/0-1A	955	958	4	12
11/15/84	FE-0ABC	FE-9/0-1B	959	962	4	4
10/18/84	FE-0ABC	FE-9/0-2A	795	810	16	16
10/19/84	FE-0ABC	FE-9/0-2B	811	822	12	12
10/15/84	FE-0ABC	FE-9/0-3A	735	754	20	20
10/12/84	FE-0ABC	FE-9/0-3B	712	734	20	20
10/16/84	FE-0ABC	FE-9/0-4A	755	774	20	20
10/17/84	FE-0ABC	FE-9/0-4B	775	794	20	20
10/22/84	FE-0ABC	FE-9/0-5A	827	838	12	
10/30/84	FE-0ABC	FE-9/0-5A	899	906	8	20
10/23/84	FE-0ABC	FE-9/0-5B	839	850	12	
10/30/84	FE-0ABC	FE-9/0-5B	891	898	8	20
10/24/84	FE-0ABC	FE-9/0-6A	851	858	8	
10/29/84	FE-0ABC	FE-9/0-6A	879	890	12	20
10/24/84	FE-0ABC	FE-9/0-6B	859	866	8	
10/26/84	FE-0ABC	FE-9/0-6B	867	878	12	20
					Total Test Runs	204

Table 27. Inventory of observation runs -- Continued

Date	Meter Tube	Orifice Plate	Deleted Runs Run No. Beg.	End	Num. of Runs	Comments
11/08/84	FE-0ABC	FE-9/0-1A	923	930	8	diff. pressure pulsations of approx. 4 in. of water pulsations obs. by operating personnel
11/08/84	FE-0ABC	FE-9/0-1B	931	946	16	
11/09/84	FE-0ABC	FE-9/0-1B	947	950	4	
11/09/84	FE-0ABC	FE-9/0-1A	951	954	4	
11/06/84	FE-0ABC	FE-9/0-2A	907	910	4	transducer malfunction
11/16/84	FE-0ABC	FE-9/0-2A	963	966	4	bad static pressure calibration
11/06/84	FE-0ABC	FE-9/0-2B	911	914	4	bad static pressure calibration
11/16/84	FE-0ABC	FE-9/0-2B	967	970	4	
10/19/84	FE-0ABC	FE-9/0-2B	823-826			These test runs were recorded incorrectly and could not be properly analyzed.
10/12/84	FE-0ABC	FE-9/0-3B	724	726	4	data lost - conflict with chromatograph print cycle

C. Presentation of the Data Analysis Results

The results of the test run data analysis are presented in tabular and graphical form. Tabulation for each test run is limited to a single line. Computation of discharge coefficients or Reynolds number from the values listed for each test run is not possible due to the finite extent of the tables and the number of intermediate parameters necessary to do so. Those interested in a greater level of analytical detail may consult the archival database which contains all of the observed data.

Four sets of data tables are ordered by meter tube and orifice plate. Tables 28 - 31 tabulate the results for each meter tube tested with each orifice plate's results contained in a table subsection. The tables are ordered according to the meter designation, i.e., beginning with the 6-inch mild steel meter tube, FE-7ABC, in table 28, and ending with the second 10-inch meter tube, FE-0ABC. The electroless nickel-plated, 6-inch mild steel meter tube is designated PE-8ABC, and its test run results are given in table 29. The measured diameter values for the meter tube and plate and the resulting beta ratio are listed in the heading for each page of the table. The contents of the table's columns are the following:

Run No. - Test run number.
Date - Observation date.
Orifice Temp. - Temperature of the flowing fluid observed approximately five diameters from the orifice union.
Orifice Press. - Orifice absolute pressure observed at the downstream orifice tap (psia).
Orifice Density - Density of the natural gas computed for the orifice temperature, pressure, and composition conditions.
Differential Pressure
  Mean - Average of the means of the observed values for the high or low range transducer set. The set selected is that appropriate to the differential pressure, i.e., for differential pressures below 40 inches of water, the low range transducer values were selected. For differential pressures above that, the high range transducer values were selected. The values given in parenthesis are given in pressure units of inches of water at 4 °C. The values give in the second column are given in pressure units of pounds per square inch (psi).
  Std. Dev. - The pooled standard deviation of the mean values of the two observation sets in pressure units of psi. Three standard deviations are used in the pooling.
Mass Flow Rate
  Total - The total mass flow rate computed for the nozzles in use.
  Rand. - The random error component derived from the

propagation of errors analysis.

Syst. - The larger of the systematic error components, including estimated effects of throat temperature differences between calibration and use conditions.

Coefficients

Mean - Average discharge coefficient values obtained from the corresponding differential pressure measurement.

Rand. - Random uncertainty in the discharge coefficient value taken from the propagation of errors analysis. This is the pooled estimate obtained from the mean of the random uncertainties computed from the two arrays of differential pressure observations (three standard deviation value). The pooled estimate is obtained from the mean of the two variances, i.e., $s_p = \left(\frac{s_1^2 + s_2^2}{2}\right)^{1/2}$ where

s_1 and s_2 are the absolute uncertainties derived from each differential pressure transducer's array of response data.

Syst. - The systematic uncertainty in the discharge coefficient value taken from the propagation of errors analysis using the larger of the two systematic uncertainties in mass flow rate. The value given is the mean value.

Reynolds Number - Pipe Reynolds number based on the meter diameter.

Gas and Nozzle Number - Gas type is indicated in the first column with an "A" for Amarillo gas, i.e., approximately 90 mole percent methane concentration or a "G" for Gulf Coast gas having approximately 95 percent methane concentration.
The number of nozzles in operation is given in the second column.

Throat Pressure and Temperature - The average values computed for the nozzle throat pressure and temperature.

The results of the analysis are also plotted for each orifice plate. The plots are placed after the table section for each meter tube and are ordered sequentially by beta ratio. The following subsections contain plots and tabulations for each meter tube and orifice plate.

Table 28A. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-1B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 1.2496 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.20618 (1984), 0.20418 (1985)

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge Coefficient ---- Mean	Rand.	Syst.	Pipe Rey. Number	Gas/	Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
501	09/10/84	77.42	682.53	2.1863	(6.1)	0.2206	0.0028	0.33862	0.00052	0.00100	0.5942	0.0040	0.0026	102,825	G	1	370	-0.2
502	09/10/84	79.30	681.83	2.1735	(6.1)	0.2214	0.0026	0.33782	0.00052	0.00100	0.5934	0.0037	0.0026	102,356	G	1	370	0.6
503	09/10/84	81.03	681.14	2.1616	(6.1)	0.2204	0.0029	0.33703	0.00052	0.00101	0.5950	0.0041	0.0026	101,911	G	1	369	1.5
504	09/10/84	82.63	680.20	2.1498	(6.1)	0.2211	0.0027	0.33616	0.00052	0.00101	0.5942	0.0039	0.0026	101,462	G	1	369	2.4
505	09/11/84	95.18	637.17	1.9373	(17.4)	0.6286	0.0050	0.53990	0.00157	0.00173	0.5960	0.0032	0.0028	161,418	G	1	346	17.5
506	09/11/84	95.10	637.40	1.9385	(17.5)	0.6299	0.0048	0.54017	0.00157	0.00173	0.5955	0.0031	0.0028	161,509	G	1	346	17.5
507	09/11/84	94.96	638.20	1.9417	(17.6)	0.6358	0.0192	0.54086	0.00163	0.00173	0.5930	0.0092	0.0028	161,724	G	1	346	17.4
508	09/11/84	95.24	647.90	1.9717	(17.8)	0.6435	0.0022	0.54910	0.00159	0.00176	0.5938	0.0023	0.0028	163,910	G	1	352	17.8
509	09/11/84	91.42	653.98	2.0093	(44.0)	1.5868	0.0093	0.87305	0.00188	0.00277	0.5955	0.0024	0.0027	261,619	G	2	355	15.0
510	09/11/84	90.63	655.13	2.0170	(44.0)	1.5892	0.0093	0.87539	0.00188	0.00277	0.5955	0.0024	0.0027	262,540	G	2	355	14.3
511	09/11/84	89.88	656.19	2.0241	(44.1)	1.5908	0.0093	0.87763	0.00189	0.00277	0.5957	0.0024	0.0027	263,415	G	2	356	13.7
512	09/11/84	89.21	657.21	2.0308	(44.2)	1.5935	0.0093	0.87981	0.00189	0.00277	0.5957	0.0024	0.0027	264,249	G	2	357	13.1
513	09/12/84	87.13	660.15	2.0553	(91.8)	3.3145	0.0122	1.27546	0.00285	0.00388	0.5949	0.0020	0.0026	383,769	G	1	357	9.5
514	09/12/84	87.44	658.13	2.0470	(91.6)	3.3047	0.0121	1.27099	0.00285	0.00387	0.5949	0.0020	0.0026	382,392	G	1	356	9.7
515	09/12/84	87.43	656.08	2.0401	(91.2)	3.2918	0.0118	1.26673	0.00285	0.00386	0.5950	0.0020	0.0027	381,228	G	1	355	9.8
516	09/12/84	87.11	654.24	2.0356	(90.9)	3.2822	0.0123	1.25797	0.02017	0.00389	0.5924	0.0096	0.0027	378,839	G	1	354	12.8
517	09/12/84	87.22	648.55	2.0152	(141.4)	5.1041	0.0105	1.56774	0.00292	0.00480	0.5947	0.0016	0.0027	472,473	G	2	352	9.9
518	09/12/84	87.06	647.05	2.0111	(141.1)	5.0912	0.0106	1.56417	0.00292	0.00479	0.5947	0.0016	0.0027	471,596	G	2	351	9.8
519	09/12/84	87.03	646.25	2.0086	(140.9)	5.0858	0.0105	1.56213	0.00292	0.00478	0.5946	0.0016	0.0027	471,053	G	2	350	9.8
520	09/12/84	87.40	645.35	2.0038	(140.7)	5.0773	0.0106	1.55938	0.00292	0.00478	0.5948	0.0016	0.0027	470,065	G	2	350	10.1
397	09/23/85	87.43	720.90	2.2928	(64.4)	2.3242	0.0176	1.13788	0.00118	0.00349	0.6003	0.0025	0.0026	335,512	G	3	391	9.7
398	09/23/85	87.10	720.82	2.2944	(64.9)	2.3409	0.0067	1.13817	0.00118	0.00349	0.5981	0.0014	0.0026	335,732	G	3	391	9.4
399	09/23/85	87.01	720.74	2.2946	(64.9)	2.3408	0.0091	1.13819	0.00118	0.00349	0.5981	0.0016	0.0026	335,779	G	3	391	9.3
400	09/23/85	87.02	720.65	2.2942	(64.9)	2.3427	0.0059	1.13809	0.00118	0.00349	0.5978	0.0013	0.0026	335,748	G	3	391	9.3
401	09/23/85	87.28	698.46	2.2139	(200.3)	7.2303	0.0405	1.96587	0.00255	0.00600	0.5975	0.0021	0.0026	581,696	G	2	379	9.6
402	09/23/85	87.41	698.83	2.2144	(201.3)	7.2666	0.0116	1.96641	0.00255	0.00600	0.5961	0.0013	0.0026	581,730	G	2	379	9.8
403	09/23/85	87.29	698.80	2.2150	(201.2)	7.2604	0.0236	1.96659	0.00255	0.00600	0.5963	0.0015	0.0026	581,868	G	2	379	9.7
404	09/23/85	87.42	698.40	2.2118	(200.7)	7.2452	0.0270	1.96450	0.00255	0.00600	0.5967	0.0016	0.0026	581,192	G	2	379	9.9
405	09/23/85	87.33	701.92	2.2238	(152.0)	5.4848	0.0069	1.71254	0.00239	0.00524	0.5966	0.0013	0.0026	506,429	G	2	380	9.8
406	09/23/85	87.64	702.23	2.2232	(152.0)	5.4855	0.0093	1.71276	0.00239	0.00524	0.5967	0.0013	0.0026	506,284	G	2	381	10.0
407	09/23/85	88.70	702.26	2.2174	(152.3)	5.4975	0.0068	1.71097	0.00240	0.00526	0.5962	0.0013	0.0026	505,104	G	2	381	10.7
408	09/23/85	90.60	702.67	2.2072	(152.4)	5.4990	0.0066	1.70767	0.00238	0.00529	0.5963	0.0013	0.0026	502,980	G	2	381	12.3

Table 28A. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-1B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 1.2496 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.20618 (1984), 0.20418 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
409	09/23/85	90.85	703.48	2.2090	(120.5)	4.3486	0.0067	1.51621	0.00230	0.00467	0.5953	0.0014	0.0026	446,379	G 2	381	11.8
410	09/23/85	91.00	703.03	2.2067	(120.4)	4.3460	0.0066	1.51491	0.00230	0.00467	0.5953	0.0014	0.0026	445,946	G 2	381	11.9
411	09/23/85	91.52	703.15	2.2043	(120.5)	4.3494	0.0062	1.51427	0.00229	0.00468	0.5952	0.0013	0.0026	445,472	G 2	381	12.2
412	09/23/85	91.80	703.24	2.2031	(120.5)	4.3476	0.0066	1.51388	0.00229	0.00469	0.5953	0.0014	0.0026	445,201	G 2	381	12.5
513	10/07/85	89.99	662.21	2.0724	(190.9)	6.8899	0.0078	1.85129	0.00260	0.00574	0.5957	0.0014	0.0027	549,815	G 2	359	12.5
514	10/07/85	90.01	662.17	2.0721	(190.8)	6.8875	0.0077	1.85104	0.00260	0.00574	0.5958	0.0014	0.0027	549,729	G 2	359	12.6
515	10/07/85	89.96	661.66	2.0706	(190.7)	6.8809	0.0073	1.84970	0.00260	0.00573	0.5958	0.0014	0.0027	549,406	G 2	359	12.6
516	10/07/85	90.03	661.45	2.0696	(190.5)	6.8763	0.0089	1.84894	0.00260	0.00573	0.5959	0.0014	0.0027	549,151	G 2	359	12.6
517	10/07/85	91.91	672.22	2.0943	(12.4)	0.4489	0.0018	0.47303	0.00072	0.00148	0.5944	0.0018	0.0027	139,966	G 2	365	13.1
518	10/07/85	92.66	673.11	2.0935	(12.5)	0.4494	0.0019	0.47329	0.00072	0.00148	0.5945	0.0018	0.0027	139,899	G 2	365	13.7
519	10/07/85	93.25	673.83	2.0929	(12.5)	0.4499	0.0019	0.47348	0.00072	0.00149	0.5945	0.0018	0.0027	139,837	G 2	366	14.2
520	10/07/85	93.49	674.34	2.0935	(12.5)	0.4494	0.0018	0.47371	0.00072	0.00149	0.5950	0.0018	0.0027	139,854	G 2	366	14.5
521	10/07/85	89.75	669.28	2.0946	(145.1)	5.2361	0.0071	1.62249	0.00249	0.00503	0.5960	0.0014	0.0027	481,589	G 2	363	12.2
522	10/07/85	89.41	669.16	2.0959	(145.0)	5.2347	0.0073	1.62292	0.00249	0.00502	0.5961	0.0014	0.0027	481,926	G 2	363	11.8
523	10/07/85	89.04	669.03	2.0973	(144.9)	5.2310	0.0077	1.62321	0.00249	0.00501	0.5962	0.0014	0.0027	482,241	G 2	363	11.5
524	10/07/85	88.80	668.94	2.0975	(145.0)	5.2334	0.0070	1.62327	0.00249	0.00501	0.5961	0.0014	0.0027	482,416	G 2	363	11.3
525	10/07/85	89.54	670.84	2.0995	(60.4)	2.1808	0.0113	1.04978	0.00124	0.00326	0.5974	0.0020	0.0027	311,623	G 3	364	11.9
526	10/07/85	88.98	670.36	2.1007	(60.5)	2.1850	0.0066	1.04959	0.00124	0.00326	0.5966	0.0015	0.0027	311,803	G 3	364	11.6
527	10/07/85	88.47	670.50	2.1039	(60.5)	2.1850	0.0065	1.05045	0.00124	0.00325	0.5966	0.0015	0.0027	312,248	G 3	364	11.1
528	10/07/85	88.28	671.33	2.1076	(60.6)	2.1876	0.0066	1.05214	0.00124	0.00325	0.5967	0.0015	0.0027	312,785	G 3	364	10.9
700	10/31/85	93.47	600.71	1.8441	(11.0)	0.3985	0.0017	0.41965	0.00076	0.00132	0.5964	0.0020	0.0028	125,036	G 2	326	14.2
701	10/31/85	93.80	601.23	1.8444	(11.1)	0.3997	0.0017	0.42011	0.00076	0.00132	0.5961	0.0020	0.0028	125,112	G 2	326	14.0
702	10/31/85	94.08	601.60	1.8444	(11.1)	0.4005	0.0016	0.42033	0.00076	0.00132	0.5958	0.0019	0.0028	125,128	G 2	327	14.1
703	10/31/85	94.16	601.91	1.8451	(11.1)	0.4008	0.0016	0.42051	0.00076	0.00133	0.5957	0.0020	0.0028	125,163	G 2	327	14.2
704	10/31/85	93.31	602.34	1.8507	(39.9)	1.4402	0.0071	0.80487	0.00177	0.00596	0.6004	0.0023	0.0054	239,761	G 2	327	14.7
705	10/31/85	92.85	602.70	1.8539	(40.2)	1.4491	0.0036	0.80581	0.00123	0.00255	0.5988	0.0016	0.0028	240,169	G 2	327	14.3
706	10/31/85	92.93	602.84	1.8540	(40.1)	1.4490	0.0035	0.80596	0.00123	0.00255	0.5989	0.0016	0.0028	240,182	G 2	327	14.3
707	10/31/85	92.75	602.61	1.8540	(40.1)	1.4479	0.0035	0.80573	0.00123	0.00255	0.5989	0.0016	0.0028	240,157	G 2	327	14.2
708	10/31/85	93.70	599.75	1.8406	(102.8)	3.7096	0.0041	1.27635	0.00217	0.00400	0.5944	0.0015	0.0028	380,095	G 2	325	14.9
709	10/31/85	93.92	599.13	1.8376	(102.7)	3.7052	0.0044	1.27457	0.00217	0.00400	0.5944	0.0015	0.0028	379,493	G 2	325	15.2
710	10/31/85	94.00	598.55	1.8354	(102.5)	3.7000	0.0046	1.27309	0.00216	0.00400	0.5945	0.0015	0.0028	379,045	G 2	325	15.3
711	10/31/85	94.09	598.24	1.8348	(102.5)	3.6991	0.0046	1.27253	0.00216	0.00400	0.5944	0.0015	0.0028	378,818	G 2	324	15.4

Table 28A. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-1B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 1.2496 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.20618 (1984), 0.20418 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand.	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
								(pounds/second)									
712	10/31/85	94.72	596.60	1.8271	(153.2)	5.5307	0.0050	1.55676	0.00230	0.00493	0.5956	0.0015	0.0028	463,135	G 3	324	16.1
713	10/31/85	95.23	595.78	1.8224	(152.8)	5.5146	0.0130	1.55367	0.00228	0.00493	0.5960	0.0016	0.0028	461,942	G 3	323	16.5
714	10/31/85	95.14	595.72	1.8226	(152.9)	5.5170	0.0052	1.55354	0.00228	0.00493	0.5958	0.0015	0.0028	461,960	G 3	323	16.6
715	10/31/85	94.97	595.96	1.8241	(152.2)	5.4936	0.0279	1.55440	0.00228	0.00493	0.5972	0.0021	0.0028	462,299	G 3	323	16.5
716	10/31/85	95.24	595.52	1.8226	(198.4)	7.1616	0.0232	1.77104	0.00237	0.00562	0.5958	0.0017	0.0028	526,519	G 3	323	17.1
717	10/31/85	94.97	595.50	1.8237	(198.7)	7.1697	0.0079	1.77145	0.00237	0.00562	0.5954	0.0014	0.0028	526,822	G 3	323	16.9
718	10/31/85	95.05	595.69	1.8240	(198.8)	7.1739	0.0055	1.77203	0.00237	0.00562	0.5954	0.0014	0.0028	526,930	G 3	323	16.9
719	10/31/85	95.24	595.85	1.8237	(198.8)	7.1738	0.0060	1.77225	0.00237	0.00563	0.5955	0.0014	0.0028	526,855	G 3	323	17.0

Table 28B. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 2.2500 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.37125 (1984), 0.36765 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
344	08/15/84	82.27	714.07	2.2698	(9.2)	0.3311	0.0022	1.39466	0.00274	0.00414	0.5992	0.0025	0.0025	418,846	G 1	386	5.0
345	08/15/84	82.25	714.43	2.2717	(9.2)	0.3313	0.0022	1.39555	0.00275	0.00414	0.5992	0.0025	0.0025	419,080	G 1	387	5.0
346	08/15/84	82.36	714.81	2.2720	(9.2)	0.3316	0.0022	1.39604	0.00274	0.00414	0.5991	0.0025	0.0025	419,166	G 1	387	5.2
347	08/15/84	82.33	715.23	2.2736	(9.2)	0.3317	0.0022	1.39680	0.00274	0.00415	0.5991	0.0025	0.0025	419,380	G 1	387	5.2
348	08/15/84	82.23	715.55	2.2752	(9.2)	0.3318	0.0022	1.39753	0.00275	0.00415	0.5991	0.0025	0.0025	419,627	G 1	387	5.2
349	08/15/84	82.10	715.91	2.2773	(9.2)	0.3317	0.0022	1.39836	0.00275	0.00415	0.5993	0.0025	0.0025	419,920	G 1	387	5.2
350	08/15/84	80.38	716.76	2.2903	(38.2)	1.3789	0.0022	2.85980	0.00397	0.00871	0.5993	0.0013	0.0025	860,421	G 1	389	3.8
351	08/15/84	80.63	717.33	2.2908	(38.2)	1.3804	0.0022	2.86158	0.00397	0.00872	0.5993	0.0013	0.0025	860,617	G 1	389	3.9
352	08/15/84	80.67	717.82	2.2927	(38.3)	1.3813	0.0022	2.86359	0.00397	0.00873	0.5992	0.0013	0.0025	861,102	G 1	389	4.0
353	08/15/84	80.44	718.33	2.2959	(38.3)	1.3825	0.0022	2.86674	0.00398	0.00873	0.5992	0.0013	0.0025	862,231	G 1	390	3.7
354	08/15/84	80.92	718.75	2.2945	(38.3)	1.3835	0.0022	2.86718	0.00397	0.00874	0.5993	0.0013	0.0025	861,803	G 1	390	4.0
355	08/15/84	80.99	719.15	2.2950	(38.4)	1.3842	0.0022	2.86820	0.00397	0.00875	0.5993	0.0013	0.0025	862,011	G 1	390	4.2
586	09/20/84	86.32	667.47	2.0627	(18.0)	0.6482	0.0029	1.85596	0.00260	0.00565	0.5978	0.0019	0.0026	559,367	G 2	362	9.1
587	09/20/84	86.18	667.59	2.0638	(17.9)	0.6472	0.0027	1.85620	0.00311	0.00565	0.5982	0.0019	0.0026	559,528	G 2	362	9.1
588	09/20/84	86.22	667.30	2.0626	(17.9)	0.6475	0.0027	1.85104	0.02296	0.00568	0.5965	0.0076	0.0026	557,969	G 2	362	10.3
589	09/20/84	86.28	666.73	2.0604	(17.9)	0.6465	0.0027	1.87467	0.03728	0.00547	0.6050	0.0121	0.0025	565,096	G 2	361	3.4
590	09/20/84	84.32	662.16	2.0547	(52.4)	1.8924	0.0075	3.17125	0.00475	0.00982	0.5988	0.0018	0.0026	958,861	G 2	359	7.4
591	09/20/84	84.34	661.39	2.0529	(52.4)	1.8898	0.0077	3.16792	0.00474	0.00980	0.5988	0.0018	0.0026	957,934	G 2	359	7.4
592	09/20/84	84.15	660.26	2.0500	(52.3)	1.8871	0.0078	3.16288	0.00475	0.00978	0.5987	0.0018	0.0026	956,799	G 2	358	7.3
593	09/20/84	83.53	658.74	2.0480	(52.1)	1.8810	0.0079	3.15709	0.00475	0.00974	0.5989	0.0019	0.0026	955,991	G 2	357	6.8
594	09/20/84	81.86	652.06	2.0342	(139.2)	5.0243	0.0071	5.15403	0.01047	0.02413	0.5996	0.0016	0.0036	1,565,482	G 1	354	5.2
595	09/20/84	81.25	651.53	2.0355	(139.1)	5.0207	0.0070	5.15269	0.01048	0.02409	0.5995	0.0016	0.0036	1,566,385	G 1	354	4.8
596	09/20/84	81.10	650.78	2.0337	(139.0)	5.0161	0.0071	5.14815	0.01048	0.02405	0.5995	0.0016	0.0036	1,565,477	G 1	353	4.5
597	09/20/84	81.35	650.09	2.0301	(138.8)	5.0102	0.0070	5.14138	0.01047	0.02403	0.5996	0.0016	0.0036	1,563,100	G 1	353	4.7
598	09/21/84	86.43	698.17	2.1672	(18.7)	0.6744	0.0018	1.94547	0.00298	0.00591	0.5993	0.0016	0.0025	583,585	G 2	378	8.9
599	09/21/84	86.35	697.67	2.1659	(18.7)	0.6739	0.0018	1.94413	0.00298	0.00590	0.5993	0.0016	0.0025	583,282	G 2	378	8.9
600	09/21/84	86.25	697.17	2.1648	(18.7)	0.6732	0.0018	1.94283	0.00298	0.00590	0.5994	0.0016	0.0025	583,008	G 2	377	8.8
601	09/21/84	86.34	696.63	2.1625	(18.6)	0.6729	0.0018	1.94109	0.00298	0.00590	0.5993	0.0016	0.0025	582,473	G 2	377	8.9
602	09/21/84	87.11	695.37	2.1542	(8.9)	0.3208	0.0017	1.33991	0.00275	0.00407	0.6004	0.0023	0.0026	401,775	G 1	376	9.7
603	09/21/84	86.80	695.11	2.1550	(8.9)	0.3203	0.0017	1.33967	0.00275	0.00407	0.6006	0.0023	0.0026	401,868	G 1	376	9.5
604	09/21/84	86.60	694.89	2.1553	(8.9)	0.3202	0.0017	1.33950	0.00275	0.00407	0.6006	0.0023	0.0026	401,926	G 1	376	9.3
605	09/21/84	85.92	694.25	2.1567	(8.9)	0.3196	0.0017	1.33901	0.00275	0.00406	0.6007	0.0023	0.0026	402,152	G 1	375	8.9

Table 28B. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 2.2500 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.37125 (1984), 0.36765 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand. (pounds/second)	Syst.	Coefficient Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
606	09/21/84	81.82	689.14	2.1615	(107.5)	3.8796	0.0056	4.65641	0.00576	0.01410	0.5983	0.0013	0.0025	1,406,608	G 3	373	5.0
607	09/21/84	81.53	688.87	2.1621	(107.4)	3.8774	0.0056	4.65580	0.00576	0.01408	0.5983	0.0013	0.0025	1,406,969	G 3	373	4.8
608	09/21/84	81.16	688.58	2.1632	(107.4)	3.8756	0.0056	4.65616	0.00577	0.01406	0.5984	0.0013	0.0025	1,407,786	G 3	373	4.4
609	09/21/84	80.93	688.34	2.1636	(107.4)	3.8745	0.0057	4.65597	0.00577	0.01404	0.5984	0.0013	0.0025	1,408,179	G 3	373	4.2

Table 28C. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 2.2499 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.37123 (1984), 0.36763 (1985)

Run No.	Date	Orifice Temp. (°F)	Orifice Press. (Psia)	Orifice Density (lb/CF)	Diff. Press. (in.)	Diff. Press. Mean (psi)	Diff. Press. Std. Dev. (psi)	Mass Flow Rate Total (pounds/second)	Mass Flow Rate Rand. (pounds/second)	Mass Flow Rate Syst. (pounds/second)	Discharge Coefficient Mean	Discharge Coefficient Rand.	Discharge Coefficient Syst.	Pipe Rey. Number	Gas/	Num. Noz.	Throat Press. (Psia)	Throat Temp. (°F)°
374	08/16/84	83.46	704.41	2.2422	(9.0)	0.3262	0.0022	1.37622	0.00181	0.00411	0.5995	0.0024	0.0025	411,932	G	1	381	6.3
375	08/16/84	83.39	705.26	2.2461	(9.0)	0.3264	0.0023	1.37804	0.00181	0.00412	0.5996	0.0024	0.0025	412,444	G	1	382	6.3
376	08/16/84	83.28	706.12	2.2497	(9.1)	0.3268	0.0022	1.37986	0.00181	0.00412	0.5995	0.0024	0.0025	412,988	G	1	382	6.3
377	08/16/84	83.16	706.90	2.2528	(9.1)	0.3270	0.0022	1.38147	0.00181	0.00412	0.5996	0.0024	0.0025	413,527	G	1	382	6.3
378	08/16/84	83.05	707.69	2.2561	(9.1)	0.3274	0.0023	1.38310	0.00182	0.00413	0.5995	0.0024	0.0025	414,020	G	1	383	6.2
379	08/16/84	82.93	708.50	2.2596	(9.1)	0.3278	0.0022	1.38491	0.00182	0.00413	0.5994	0.0024	0.0025	414,570	G	1	383	6.2
380	08/20/84	87.65	666.97	2.0795	(8.5)	0.3077	0.0019	1.28962	0.00201	0.00393	0.6005	0.0023	0.0026	387,425	G	1	361	9.9
381	08/20/84	87.76	666.84	2.0780	(8.5)	0.3075	0.0019	1.28881	0.00201	0.00393	0.6005	0.0023	0.0026	387,134	G	1	361	10.1
382	08/20/84	87.71	666.71	2.0778	(8.5)	0.3075	0.0019	1.28839	0.00201	0.00393	0.6004	0.0023	0.0026	387,038	G	1	361	10.2
383	08/20/84	88.04	666.58	2.0756	(8.5)	0.3075	0.0019	1.28768	0.00201	0.00393	0.6004	0.0023	0.0026	386,683	G	1	361	10.5
384	08/20/84	88.17	666.44	2.0745	(8.5)	0.3074	0.0019	1.28700	0.00201	0.00394	0.6003	0.0023	0.0026	386,420	G	1	361	10.7
385	08/20/84	87.99	666.34	2.0751	(8.5)	0.3071	0.0019	1.28680	0.00201	0.00394	0.6004	0.0023	0.0026	386,453	G	1	361	10.7
386	08/20/84	84.24	665.30	2.0898	(35.3)	1.2748	0.0020	2.62815	0.00276	0.00818	0.5996	0.0012	0.0026	793,078	G	1	361	7.8
387	08/20/84	83.58	665.30	2.0933	(35.3)	1.2744	0.0019	2.63019	0.00276	0.00817	0.5997	0.0012	0.0026	794,343	G	1	361	7.2
388	08/20/84	82.93	665.20	2.0967	(35.3)	1.2743	0.0020	2.63210	0.00276	0.00815	0.5997	0.0012	0.0026	795,565	G	1	361	6.6
389	08/20/84	83.04	665.06	2.0956	(35.3)	1.2749	0.0019	2.63173	0.00276	0.00814	0.5996	0.0012	0.0026	795,357	G	1	361	6.6
390	08/20/84	82.86	664.87	2.0958	(35.3)	1.2749	0.0019	2.63139	0.00276	0.00814	0.5995	0.0012	0.0026	795,452	G	1	361	6.4
391	08/20/84	82.77	664.72	2.0957	(35.3)	1.2745	0.0020	2.63140	0.00276	0.00813	0.5996	0.0012	0.0026	795,543	G	1	361	6.3
413	09/24/85	88.94	684.44	2.1550	(11.0)	0.3984	0.0013	1.47699	0.00194	0.00452	0.5940	0.0016	0.0025	437,310	G	2	371	10.5
414	09/24/85	88.86	687.82	2.1670	(11.1)	0.3992	0.0013	1.48489	0.00193	0.00454	0.5949	0.0015	0.0025	439,473	G	2	373	10.4
415	09/24/85	88.65	690.48	2.1772	(11.1)	0.4017	0.0013	1.49124	0.00193	0.00456	0.5942	0.0015	0.0025	441,286	G	2	374	10.3
416	09/24/85	88.50	692.93	2.1857	(11.2)	0.4034	0.0014	1.49707	0.00193	0.00457	0.5941	0.0016	0.0025	442,953	G	2	376	10.2
417	09/24/85	88.94	709.62	2.2397	(22.2)	0.8025	0.0015	2.14823	0.00211	0.00659	0.5970	0.0012	0.0025	633,726	G	3	385	10.8
418	09/24/85	89.08	713.02	2.2505	(22.3)	0.8061	0.0015	2.15874	0.00211	0.00662	0.5971	0.0012	0.0025	636,395	G	3	387	10.9
419	09/24/85	89.04	715.81	2.2603	(22.4)	0.8095	0.0015	2.16773	0.00209	0.00665	0.5971	0.0012	0.0025	638,800	G	3	388	10.9
420	09/24/85	89.06	717.83	2.2671	(22.5)	0.8114	0.0015	2.17409	0.00209	0.00667	0.5972	0.0012	0.0025	640,465	G	3	389	10.9
460	09/27/85	88.75	560.33	1.7991	(44.3)	1.5992	0.0070	2.72041	0.00613	0.01679	0.5974	0.0022	0.0045	810,499	A	2	305	12.2
461	09/27/85	88.15	559.33	1.7981	(44.2)	1.5966	0.0068	2.71732	0.00419	0.00862	0.5973	0.0019	0.0027	810,325	A	2	304	11.6
462	09/27/85	88.02	558.74	1.7966	(44.2)	1.5949	0.0069	2.71494	0.00419	0.00861	0.5974	0.0020	0.0027	809,812	A	2	304	11.5
463	09/27/85	87.98	558.07	1.7948	(44.1)	1.5919	0.0069	2.71165	0.00419	0.00860	0.5975	0.0019	0.0027	808,925	A	2	303	11.5
468	09/27/85	86.87	548.01	1.7655	(143.8)	5.1897	0.0071	4.86478	0.01160	0.02249	0.5978	0.0019	0.0036	1,455,582	A	2	298	11.0
469	09/27/85	86.61	549.77	1.7726	(144.2)	5.2061	0.0071	4.88299	0.01157	0.02256	0.5979	0.0019	0.0036	1,461,177	A	2	299	10.8
470	09/27/85	86.25	551.08	1.7787	(144.6)	5.2202	0.0069	4.89723	0.01158	0.02260	0.5978	0.0019	0.0036	1,465,860	A	2	300	10.5
471	09/27/85	85.96	552.50	1.7840	(145.0)	5.2321	0.0070	4.91214	0.01159	0.02264	0.5981	0.0019	0.0036	1,470,204	A	2	301	10.1

Table 28C. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 2.2499 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.37123 (1984), 0.36763 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/	Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
472	09/27/85	86.56	544.77	1.7564	(188.0)	6.7838	0.0081	5.43674	0.01173	0.02418	0.5855	0.0017	0.0034	1,628,302	A	2	297	10.9
473	09/27/85	86.25	543.99	1.7550	(187.7)	6.7731	0.0080	5.42981	0.01172	0.02413	0.5855	0.0017	0.0034	1,627,064	A	2	296	10.7
474	09/27/85	85.75	543.82	1.7565	(187.6)	6.7696	0.0080	5.43102	0.01172	0.02411	0.5855	0.0017	0.0034	1,628,536	A	2	296	10.3
475	09/27/85	85.90	543.79	1.7558	(187.6)	6.7705	0.0084	5.43102	0.01466	0.03388	0.5847	0.0020	0.0045	1,628,224	A	2	296	10.3
476	09/27/85	86.05	547.28	1.7679	(97.6)	3.5209	0.0072	4.01387	0.00479	0.01257	0.5988	0.0015	0.0027	1,202,540	A	4	298	10.4
477	09/27/85	85.55	547.50	1.7708	(97.5)	3.5203	0.0075	4.01778	0.00479	0.01256	0.5990	0.0015	0.0027	1,204,467	A	4	298	10.0
478	09/27/85	85.29	547.68	1.7725	(97.6)	3.5215	0.0072	4.02072	0.00686	0.02158	0.5990	0.0017	0.0041	1,205,728	A	4	298	9.7
479	09/27/85	85.22	548.00	1.7733	(97.6)	3.5222	0.0076	4.02310	0.00686	0.01979	0.5987	0.0017	0.0038	1,206,562	A	4	298	9.6
480	09/27/85	83.90	546.08	1.7720	(180.5)	6.5132	0.0075	5.46814	0.01176	0.02411	0.5984	0.0018	0.0035	1,643,325	A	2	297	8.5
481	09/27/85	83.65	546.54	1.7746	(180.6)	6.5183	0.0080	5.47412	0.01176	0.02412	0.5984	0.0018	0.0035	1,645,550	A	2	298	8.3
482	09/27/85	83.65	547.07	1.7765	(180.8)	6.5268	0.0076	5.47993	0.01177	0.02414	0.5983	0.0018	0.0035	1,647,177	A	2	298	8.3
483	09/27/85	83.68	547.92	1.7793	(181.1)	6.5357	0.0081	5.48883	0.01177	0.02418	0.5984	0.0018	0.0035	1,649,591	A	2	298	8.3
678	10/30/85	96.58	670.75	2.0612	(10.8)	0.3885	0.0012	1.43026	0.00290	0.00452	0.5955	0.0019	0.0026	420,441	G	2	364	17.0
679	10/30/85	94.59	671.10	2.0721	(10.8)	0.3884	0.0012	1.43402	0.00291	0.00450	0.5956	0.0019	0.0026	422,548	G	2	364	15.5
680	10/30/85	92.64	671.46	2.0831	(10.8)	0.3884	0.0012	1.43784	0.00292	0.00447	0.5956	0.0019	0.0026	424,661	G	2	364	14.0
681	10/30/85	90.19	672.11	2.0980	(10.8)	0.3885	0.0012	1.44339	0.00293	0.00444	0.5958	0.0019	0.0026	427,536	G	2	364	12.0
682	10/30/85	86.98	670.00	2.1074	(36.1)	1.3030	0.0027	2.65183	0.00596	0.00830	0.5962	0.0018	0.0026	788,859	G	1	364	8.8
683	10/30/85	91.07	667.90	2.0793	(36.1)	1.3016	0.0033	2.63383	0.00592	0.00835	0.5964	0.0019	0.0026	779,821	G	1	362	11.4
684	10/30/85	93.42	666.25	2.0621	(36.0)	1.2994	0.0029	2.61782	0.00586	0.00841	0.5957	0.0019	0.0027	773,034	G	1	362	13.9
685	10/30/85	93.84	665.26	2.0567	(35.9)	1.2953	0.0028	2.61091	0.00585	0.00842	0.5958	0.0019	0.0027	770,705	G	1	361	14.7
686	10/30/85	93.14	660.60	2.0435	(103.3)	3.7266	0.0053	4.42830	0.00664	0.01413	0.5973	0.0015	0.0027	1,309,198	G	3	358	15.1
688	10/30/85	93.64	660.58	2.0397	(103.3)	3.7277	0.0051	4.42409	0.00663	0.01415	0.5972	0.0015	0.0027	1,307,147	G	3	358	15.6
689	10/30/85	93.72	660.45	2.0380	(103.3)	3.7269	0.0050	4.42166	0.00663	0.01416	0.5972	0.0015	0.0027	1,306,334	G	3	358	15.7
690	10/30/85	93.47	660.25	2.0376	(103.1)	3.7227	0.0048	4.42048	0.00663	0.01414	0.5974	0.0015	0.0027	1,306,364	G	3	358	15.4
692	10/30/85	93.02	655.23	2.0239	(148.6)	5.3639	0.0055	5.28812	0.01395	0.02536	0.5971	0.0020	0.0036	1,565,037	G	2	356	14.5
693	10/30/85	93.04	654.60	2.0219	(148.4)	5.3573	0.0054	5.28318	0.01395	0.02534	0.5972	0.0020	0.0036	1,563,720	G	2	356	14.4
694	10/30/85	92.96	654.28	2.0212	(148.3)	5.3533	0.0059	5.28097	0.01395	0.02532	0.5972	0.0020	0.0036	1,563,295	G	2	355	14.4
695	10/30/85	93.06	654.19	2.0204	(148.4)	5.3546	0.0058	5.28000	0.01395	0.02532	0.5972	0.0020	0.0036	1,562,830	G	2	355	14.4
696	10/30/85	92.54	661.11	2.0470	(219.9)	7.9369	0.0050	6.47787	0.01428	0.02914	0.5974	0.0017	0.0034	1,916,782	G	2	359	14.8
697	10/30/85	92.45	662.07	2.0506	(220.2)	7.9466	0.0050	6.48822	0.01429	0.02918	0.5975	0.0017	0.0034	1,919,770	G	2	359	14.8
698	10/30/85	92.50	662.87	2.0530	(220.5)	7.9567	0.0051	6.49648	0.01429	0.02922	0.5975	0.0017	0.0034	1,921,894	G	2	360	14.7
699	10/30/85	92.94	663.80	2.0539	(220.8)	7.9687	0.0048	6.50287	0.01428	0.02928	0.5975	0.0017	0.0034	1,922,485	G	2	360	15.1

Table 28D. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.0003 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.49505 (1984), 0.49025 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/	Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
236	08/07/84	80.13	629.81	1.9842	(10.0)	0.3622	0.0017	2.49020	0.00271	0.00761	0.6023	0.0018	0.0026	759,652	G	1	342	4.0
237	08/07/84	79.91	629.92	1.9855	(10.0)	0.3623	0.0017	2.49097	0.00271	0.00761	0.6022	0.0018	0.0026	760,081	G	1	342	3.9
238	08/07/84	79.74	630.00	1.9868	(10.0)	0.3624	0.0017	2.49200	0.00271	0.00760	0.6022	0.0018	0.0026	760,541	G	1	342	3.7
239	08/07/84	79.80	630.08	1.9868	(10.0)	0.3625	0.0017	2.49227	0.00271	0.00761	0.6022	0.0018	0.0026	760,558	G	1	342	3.8
240	08/07/84	79.63	630.17	1.9880	(10.0)	0.3625	0.0017	2.49291	0.00271	0.00760	0.6023	0.0018	0.0026	760,912	G	1	342	3.7
241	08/07/84	79.47	630.23	1.9892	(10.0)	0.3626	0.0017	2.49371	0.00271	0.00760	0.6021	0.0018	0.0026	761,276	G	1	342	3.5
242	08/07/84	78.93	628.67	1.9863	(22.3)	0.8045	0.0017	3.71264	0.00315	0.01116	0.6022	0.0013	0.0026	1,134,453	G	2	341	2.9
243	08/07/84	79.73	628.38	1.9814	(22.3)	0.8044	0.0017	3.70776	0.00315	0.01118	0.6022	0.0013	0.0026	1,131,859	G	2	341	3.5
244	08/07/84	79.78	628.04	1.9798	(22.3)	0.8039	0.0017	3.70464	0.00314	0.01118	0.6021	0.0013	0.0026	1,130,920	G	2	340	3.6
245	08/07/84	79.91	627.69	1.9779	(22.3)	0.8033	0.0017	3.70205	0.00314	0.01118	0.6022	0.0013	0.0026	1,129,990	G	2	340	3.7
246	08/07/84	80.04	627.22	1.9757	(22.2)	0.8027	0.0017	3.69861	0.00314	0.01117	0.6022	0.0013	0.0026	1,128,840	G	2	340	3.9
247	08/07/84	80.06	626.57	1.9734	(22.2)	0.8018	0.0017	3.69421	0.00314	0.01116	0.6022	0.0013	0.0026	1,127,573	G	2	340	3.9
248	08/07/84	80.88	624.35	1.9621	(10.0)	0.3593	0.0017	2.46526	0.00270	0.00757	0.6021	0.0018	0.0026	751,917	G	1	339	4.8
249	08/07/84	81.14	623.53	1.9580	(9.9)	0.3589	0.0017	2.46109	0.00270	0.00756	0.6020	0.0018	0.0026	750,507	G	1	338	5.0
250	08/07/84	81.12	622.71	1.9551	(9.9)	0.3583	0.0017	2.45740	0.00270	0.00755	0.6021	0.0018	0.0026	749,476	G	1	338	5.0
251	08/07/84	81.16	621.94	1.9524	(9.9)	0.3578	0.0017	2.45418	0.00270	0.00754	0.6021	0.0018	0.0026	748,549	G	1	337	5.1
252	08/07/84	81.16	621.26	1.9501	(9.9)	0.3576	0.0017	2.45134	0.00269	0.00754	0.6020	0.0018	0.0026	747,757	G	1	337	5.1
253	08/07/84	81.18	620.58	1.9477	(9.9)	0.3571	0.0017	2.44835	0.00269	0.00753	0.6020	0.0018	0.0026	746,896	G	1	337	5.1
254	08/07/84	79.60	617.23	1.9440	(39.4)	1.4226	0.0017	4.89052	0.00627	0.02280	0.6029	0.0013	0.0036	1,495,626	G	1	335	3.8
255	08/07/84	79.23	616.75	1.9442	(39.4)	1.4215	0.0017	4.88878	0.00627	0.02277	0.6029	0.0013	0.0036	1,495,915	G	1	335	3.4
256	08/07/84	78.80	616.27	1.9446	(39.4)	1.4206	0.0017	4.88717	0.00627	0.02273	0.6028	0.0013	0.0036	1,496,356	G	1	334	3.1
257	08/07/84	78.21	615.91	1.9462	(39.3)	1.4196	0.0017	4.88754	0.00628	0.02270	0.6028	0.0013	0.0036	1,497,683	G	1	334	2.6
258	08/07/84	77.52	615.62	1.9486	(39.3)	1.4187	0.0017	4.88933	0.00628	0.02266	0.6028	0.0013	0.0036	1,499,629	G	1	334	2.0
259	08/07/84	77.95	615.41	1.9457	(39.3)	1.4191	0.0017	4.88624	0.01145	0.06391	0.6028	0.0017	0.0087	1,497,897	G	1	344	2.2
308	08/10/84	82.98	664.90	2.0907	(10.6)	0.3811	0.0017	2.62964	0.00214	0.00812	0.6041	0.0017	0.0026	794,965	G	1	361	6.1
309	08/10/84	82.85	665.04	2.0930	(10.6)	0.3810	0.0018	2.63129	0.00214	0.00812	0.6042	0.0017	0.0026	795,537	G	1	361	6.0
310	08/10/84	82.57	665.18	2.0949	(10.6)	0.3813	0.0017	2.63268	0.00214	0.00811	0.6041	0.0017	0.0026	796,197	G	1	361	5.8
311	08/10/84	82.37	665.26	2.0963	(10.6)	0.3815	0.0017	2.63384	0.00214	0.00811	0.6039	0.0017	0.0026	796,743	G	1	361	5.6
312	08/10/84	82.40	665.33	2.0963	(10.6)	0.3814	0.0017	2.63399	0.00214	0.00811	0.6040	0.0017	0.0026	796,748	G	1	361	5.6
313	08/10/84	82.01	665.36	2.0985	(10.6)	0.3815	0.0017	2.63497	0.00214	0.00810	0.6039	0.0017	0.0026	797,424	G	1	361	5.4
314	08/10/84	81.13	664.88	2.1015	(23.5)	0.8497	0.0018	3.93070	0.00267	0.01191	0.6031	0.0012	0.0026	1,190,947	G	2	360	4.6
315	08/10/84	81.22	664.93	2.1012	(23.5)	0.8498	0.0018	3.93059	0.00267	0.01191	0.6031	0.0012	0.0026	1,190,770	G	2	360	4.6
316	08/10/84	80.95	664.99	2.1027	(23.6)	0.8500	0.0018	3.93167	0.00267	0.01190	0.6030	0.0012	0.0026	1,191,475	G	2	360	4.5
317	08/10/84	80.35	665.03	2.1060	(23.5)	0.8497	0.0018	3.93461	0.00267	0.01188	0.6031	0.0012	0.0025	1,193,250	G	2	360	4.0
318	08/10/84	80.51	665.05	2.1053	(23.6)	0.8501	0.0018	3.93462	0.00267	0.01189	0.6030	0.0012	0.0025	1,193,011	G	2	360	4.0
319	08/10/84	80.75	665.13	2.1043	(23.6)	0.8505	0.0018	3.93436	0.00267	0.01189	0.6030	0.0012	0.0025	1,192,565	G	2	361	4.2

Table 28D. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.0003 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.49505 (1984), 0.49025 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/	Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
484	09/30/85	91.00	551.39	1.7697	(9.0)	0.3235	0.0024	2.19856	0.00395	0.00708	0.5965	0.0027	0.0027	654,502	A	1	300	13.8
485	09/30/85	90.75	549.83	1.7654	(8.9)	0.3228	0.0025	2.19224	0.00396	0.00706	0.5961	0.0028	0.0027	652,973	A	1	299	13.8
486	09/30/85	90.98	548.13	1.7586	(8.9)	0.3217	0.0023	2.18490	0.00396	0.00704	0.5963	0.0027	0.0027	650,742	A	1	298	13.9
488	09/30/85	91.36	533.76	1.7082	(19.1)	0.6894	0.0030	3.16585	0.00490	0.01014	0.5988	0.0020	0.0028	944,197	A	2	290	14.8
489	09/30/85	91.55	531.53	1.6998	(19.1)	0.6882	0.0028	3.15112	0.00490	0.01010	0.5979	0.0019	0.0028	939,852	A	2	289	15.0
490	09/30/85	91.59	529.06	1.6913	(19.0)	0.6848	0.0031	3.13565	0.00489	0.01006	0.5980	0.0020	0.0028	935,511	A	2	288	15.1
491	09/30/85	91.44	526.66	1.6840	(18.8)	0.6798	0.0033	3.12144	0.00488	0.01001	0.5988	0.0021	0.0028	931,707	A	2	286	15.0
492	09/30/85	91.58	518.73	1.6562	(51.7)	1.8650	0.0061	5.14234	0.01098	0.02326	0.6003	0.0020	0.0036	1,536,309	A	2	282	15.5
493	09/30/85	91.59	519.86	1.6600	(51.8)	1.8689	0.0063	5.15403	0.01097	0.02331	0.6003	0.0020	0.0036	1,539,528	A	2	283	15.5
494	09/30/85	91.71	528.86	1.6901	(52.8)	1.9049	0.0056	5.24560	0.01162	0.02373	0.5998	0.0020	0.0036	1,564,730	A	2	288	15.6
495	09/30/85	91.52	540.03	1.7290	(53.9)	1.9441	0.0055	5.36175	0.01136	0.02423	0.6000	0.0019	0.0036	1,597,326	A	2	294	15.4
497	09/30/85	92.06	572.64	1.8403	(20.4)	0.7370	0.0017	3.40315	0.00497	0.01093	0.5997	0.0016	0.0027	1,008,841	A	2	311	15.5
498	09/30/85	92.17	576.06	1.8516	(20.5)	0.7412	0.0017	3.42443	0.00496	0.01099	0.6000	0.0016	0.0027	1,014,516	A	2	313	15.4
499	09/30/85	92.63	579.01	1.8598	(20.6)	0.7450	0.0017	3.44118	0.00495	0.01106	0.6000	0.0015	0.0027	1,018,460	A	2	315	15.8
500	09/30/85	92.57	580.86	1.8664	(20.7)	0.7480	0.0018	3.45261	0.00495	0.01110	0.5997	0.0016	0.0027	1,021,654	A	2	316	15.7
501	09/30/85	82.25	579.65	1.9100	(186.3)	6.7251	0.0057	10.5214	0.02882	0.04805	0.6014	0.0020	0.0035	3,155,634	A	2	316	6.9
502	09/30/85	83.60	580.49	1.9067	(186.7)	6.7378	0.0057	10.5206	0.02879	0.04824	0.6013	0.0020	0.0035	3,149,501	A	2	316	8.0
503	09/30/85	84.79	581.33	1.9042	(186.9)	6.7472	0.0058	10.5208	0.02876	0.04842	0.6013	0.0020	0.0035	3,144,304	A	2	317	9.1
504	09/30/85	85.07	582.10	1.9056	(187.1)	6.7540	0.0059	10.5305	0.02875	0.04852	0.6013	0.0020	0.0036	3,145,716	A	2	317	9.4
505	10/01/85	88.75	571.40	1.7738	(145.9)	5.2641	0.0066	8.96812	0.01862	0.04345	0.6015	0.0017	0.0037	2,698,928	G	1	311	12.2
506	10/01/85	88.79	570.90	1.7721	(145.7)	5.2585	0.0066	8.95982	0.01860	0.04341	0.6015	0.0017	0.0037	2,696,403	G	1	311	12.3
507	10/01/85	88.65	570.29	1.7706	(145.5)	5.2517	0.0066	8.95061	0.01859	0.04336	0.6015	0.0017	0.0037	2,694,347	G	1	310	12.2
508	10/01/85	88.69	569.84	1.7690	(145.3)	5.2457	0.0066	8.94297	0.01858	0.04333	0.6017	0.0017	0.0037	2,692,081	G	1	310	12.2
658	10/29/85	94.52	675.27	2.0932	(11.0)	0.3958	0.0009	2.65173	0.00583	0.00861	0.5980	0.0018	0.0027	781,000	G	1	367	16.1
659	10/29/85	94.56	675.90	2.0951	(11.0)	0.3960	0.0010	2.65423	0.00583	0.00862	0.5981	0.0018	0.0027	781,628	G	1	367	16.2
660	10/29/85	94.46	676.27	2.0969	(11.0)	0.3959	0.0009	2.65582	0.00583	0.00862	0.5983	0.0018	0.0027	782,152	G	1	367	16.1
661	10/29/85	94.26	675.00	2.0936	(11.0)	0.3961	0.0010	2.65104	0.00583	0.00860	0.5976	0.0019	0.0027	781,098	G	1	367	16.0
662	10/29/85	92.93	672.99	2.0941	(43.7)	1.5754	0.0028	5.30288	0.01400	0.02567	0.5991	0.0020	0.0036	1,565,347	G	1	365	15.2
663	10/29/85	92.33	672.72	2.0963	(43.6)	1.5741	0.0028	5.30424	0.01400	0.02564	0.5992	0.0020	0.0036	1,566,965	G	1	365	14.7
664	10/29/85	92.16	672.33	2.0958	(43.6)	1.5738	0.0028	5.30226	0.01400	0.02561	0.5991	0.0020	0.0036	1,566,784	G	1	365	14.5
665	10/29/85	92.55	672.42	2.0941	(43.6)	1.5735	0.0028	5.30037	0.01400	0.02563	0.5992	0.0020	0.0036	1,565,466	G	1	365	14.9

Table 28D. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.0003 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.49505 (1984), 0.49025 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
666	10/29/85	90.99	670.20	2.0949	(97.6)	3.5216	0.0030	7.94059	0.01519	0.03398	0.5996	0.0016	0.0033	2,350,347	G 2	364	13.6
667	10/29/85	91.48	669.98	2.0917	(97.5)	3.5197	0.0031	7.93325	0.01519	0.03400	0.5996	0.0016	0.0033	2,346,864	G 2	364	14.0
668	10/29/85	91.35	669.19	2.0897	(97.4)	3.5162	0.0032	7.92345	0.01518	0.03396	0.5995	0.0016	0.0033	2,344,587	G 2	364	14.0
669	10/29/85	91.22	668.77	2.0889	(97.4)	3.5137	0.0032	7.91981	0.01518	0.03392	0.5995	0.0016	0.0033	2,344,053	G 2	364	13.8
670	10/29/85	87.59	655.21	2.0602	(167.8)	6.0544	0.0040	10.3596	0.02919	0.04987	0.6011	0.0020	0.0036	3,086,104	G 1	357	10.8
671	10/29/85	88.38	654.04	2.0522	(167.5)	6.0449	0.0040	10.3311	0.02914	0.04984	0.6011	0.0020	0.0036	3,075,111	G 1	356	11.4
672	10/29/85	88.45	653.05	2.0485	(167.2)	6.0345	0.0040	10.3133	0.02911	0.04977	0.6011	0.0020	0.0036	3,070,002	G 1	355	11.5
673	10/29/85	88.51	652.23	2.0455	(167.0)	6.0264	0.0040	10.2989	0.02908	0.04971	0.6011	0.0020	0.0036	3,065,830	G 1	355	11.6
674	10/29/85	87.17	647.63	2.0293	(209.3)	7.5524	0.0040	11.4873	0.02911	0.05300	0.6011	0.0019	0.0035	3,428,749	G 2	352	10.2
675	10/29/85	87.20	647.07	2.0272	(209.1)	7.5459	0.0042	11.4761	0.02910	0.05296	0.6010	0.0019	0.0035	3,425,527	G 2	352	10.2
676	10/29/85	87.28	646.63	2.0253	(208.9)	7.5409	0.0043	11.4671	0.02909	0.05293	0.6010	0.0019	0.0035	3,422,739	G 2	352	10.3
677	10/29/85	87.34	646.11	2.0233	(208.8)	7.5346	0.0042	11.4565	0.02908	0.05289	0.6010	0.0019	0.0035	3,419,536	G 2	351	10.4

Table 28E. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.0004 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.49507 (1984), 0.49026 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand.	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
332	08/13/84	91.17	703.76	2.1801	(11.2)	0.4037	0.0019	2.76256	0.00267	0.00885	0.6037	0.0018	0.0026	822,027	G 1	382	13.5
333	08/13/84	89.70	704.34	2.1893	(11.2)	0.4036	0.0019	2.76877	0.00268	0.00882	0.6039	0.0018	0.0026	825,297	G 1	382	12.4
334	08/13/84	88.17	704.87	2.1994	(11.2)	0.4036	0.0019	2.77558	0.00268	0.00879	0.6040	0.0018	0.0026	828,786	G 1	382	11.2
335	08/13/84	86.76	705.34	2.2092	(11.2)	0.4039	0.0019	2.78243	0.00269	0.00876	0.6039	0.0018	0.0026	832,164	G 1	383	10.1
336	08/13/84	85.36	705.82	2.2187	(11.2)	0.4041	0.0019	2.78903	0.00270	0.00873	0.6039	0.0018	0.0026	835,476	G 1	383	8.9
337	08/13/84	84.04	706.30	2.2276	(11.2)	0.4044	0.0019	2.79575	0.00270	0.00869	0.6039	0.0018	0.0026	838,759	G 1	383	7.7
610	09/24/84	84.90	727.85	2.2758	(11.7)	0.4216	0.0017	2.87350	0.00588	0.00890	0.6015	0.0020	0.0025	859,423	G 1	394	6.9
611	09/24/84	84.89	727.84	2.2758	(11.7)	0.4214	0.0017	2.87350	0.00588	0.00890	0.6016	0.0020	0.0025	859,426	G 1	394	6.9
612	09/24/84	85.04	727.16	2.2726	(11.7)	0.4207	0.0017	2.87011	0.00588	0.00889	0.6018	0.0020	0.0025	858,357	G 1	394	7.1
613	09/24/84	84.93	726.71	2.2717	(11.7)	0.4209	0.0018	2.86859	0.00588	0.00889	0.6015	0.0020	0.0025	858,063	G 1	394	7.1
614	09/24/84	84.31	724.95	2.2693	(25.8)	0.9304	0.0017	4.26884	0.00675	0.01305	0.6023	0.0014	0.0025	1,278,206	G 2	392	6.6
615	09/24/84	84.29	724.76	2.2688	(25.8)	0.9299	0.0017	4.26781	0.00675	0.01305	0.6024	0.0014	0.0025	1,277,966	G 2	392	6.6
616	09/24/84	84.26	724.52	2.2681	(25.8)	0.9296	0.0017	4.26652	0.00675	0.01304	0.6024	0.0014	0.0025	1,277,670	G 2	392	6.6
617	09/24/84	84.29	724.46	2.2678	(25.8)	0.9294	0.0017	4.26601	0.00675	0.01304	0.6024	0.0014	0.0025	1,277,490	G 2	392	6.6
618	09/24/84	83.34	719.84	2.2575	(46.1)	1.6639	0.0080	5.70384	0.01308	0.02674	0.6032	0.0022	0.0035	1,711,203	G 1	390	5.9
619	09/24/84	83.13	718.35	2.2536	(46.0)	1.6615	0.0082	5.69291	0.01305	0.02668	0.6030	0.0022	0.0035	1,708,742	G 1	389	5.7
620	09/24/84	83.01	717.69	2.2520	(46.0)	1.6588	0.0081	5.68838	0.01304	0.02665	0.6032	0.0022	0.0035	1,707,786	G 1	389	5.6
621	09/24/84	83.02	716.92	2.2493	(45.9)	1.6577	0.0080	5.68225	0.01304	0.02662	0.6032	0.0022	0.0035	1,706,135	G 1	389	5.6
622	09/24/84	80.89	711.71	2.2436	(102.4)	3.6953	0.0082	8.48270	0.01433	0.03494	0.6035	0.0015	0.0032	2,555,553	G 2	386	3.8
623	09/24/84	80.76	710.82	2.2413	(102.3)	3.6914	0.0081	8.47298	0.01432	0.03489	0.6035	0.0015	0.0032	2,553,372	G 2	386	3.6
624	09/24/84	80.81	710.55	2.2401	(102.3)	3.6912	0.0082	8.46989	0.01432	0.03488	0.6034	0.0015	0.0032	2,552,421	G 2	385	3.7
625	09/24/84	80.87	711.57	2.2433	(102.4)	3.6959	0.0081	8.48225	0.01434	0.03494	0.6035	0.0015	0.0032	2,555,545	G 2	386	3.7
626	09/24/84	79.14	717.01	2.2719	(157.9)	5.6982	0.0079	10.5986	0.01489	0.04102	0.6031	0.0013	0.0030	3,197,139	G 4	389	2.2
627	09/24/84	79.14	719.18	2.2794	(158.4)	5.7163	0.0079	10.6328	0.01488	0.04115	0.6031	0.0013	0.0030	3,206,387	G 4	390	2.1
628	09/24/84	79.02	722.35	2.2911	(159.1)	5.7425	0.0079	10.6835	0.01492	0.04133	0.6031	0.0013	0.0030	3,220,562	G 4	392	2.0
629	09/24/84	79.00	724.89	2.3000	(159.7)	5.7634	0.0079	10.7233	0.01493	0.04147	0.6030	0.0013	0.0030	3,231,339	G 4	393	2.0

Table 28F. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-4A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.4984 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.57724 (1984), 0.57163 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/	Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
176	08/03/84	85.98	628.47	1.9555	(20.3)	0.7328	0.0024	4.94815	0.00662	0.02349	0.6062	0.0016	0.0036	1,498,331	G	1	341	9.2
177	08/03/84	86.40	628.34	1.9533	(20.3)	0.7326	0.0024	4.94481	0.00661	0.02351	0.6062	0.0016	0.0036	1,496,551	G	1	341	9.5
178	08/03/84	86.68	628.20	1.9515	(20.3)	0.7321	0.0023	4.94198	0.00661	0.02352	0.6063	0.0016	0.0037	1,495,203	G	1	341	9.8
179	08/03/84	86.47	628.09	1.9521	(20.3)	0.7318	0.0023	4.94185	0.00661	0.02351	0.6063	0.0016	0.0037	1,495,582	G	1	341	9.8
180	08/03/84	85.57	627.94	1.9558	(20.3)	0.7311	0.0024	4.94523	0.00662	0.02348	0.6065	0.0016	0.0036	1,498,322	G	1	341	9.1
181	08/03/84	85.48	627.83	1.9558	(20.3)	0.7313	0.0024	4.94527	0.00662	0.02346	0.6064	0.0016	0.0036	1,498,604	G	1	341	9.0
182	08/03/84	85.50	627.96	1.9558	(11.2)	0.4047	0.0023	3.67896	0.00265	0.01143	0.6065	0.0020	0.0027	1,114,813	G	2	340	9.2
183	08/03/84	85.31	627.85	1.9569	(11.2)	0.4045	0.0023	3.67998	0.00265	0.01142	0.6066	0.0020	0.0026	1,115,367	G	2	340	8.9
184	08/03/84	85.32	627.74	1.9562	(11.2)	0.4048	0.0023	3.67962	0.00265	0.01141	0.6065	0.0020	0.0026	1,115,293	G	2	340	8.8
185	08/03/84	85.71	627.61	1.9539	(11.2)	0.4048	0.0023	3.67725	0.00265	0.01142	0.6064	0.0020	0.0027	1,114,049	G	2	340	9.1
186	08/03/84	85.45	627.44	1.9546	(11.2)	0.4046	0.0023	3.67694	0.00265	0.01141	0.6064	0.0020	0.0026	1,114,350	G	2	340	9.0
187	08/03/84	85.47	627.30	1.9543	(11.2)	0.4045	0.0023	3.67655	0.00265	0.01141	0.6065	0.0020	0.0026	1,114,192	G	2	340	9.0
338	08/13/84	78.88	709.07	2.2664	(12.7)	0.4598	0.0019	4.21475	0.00320	0.01263	0.6057	0.0016	0.0025	1,271,909	G	2	384	2.7
339	08/13/84	78.82	709.44	2.2679	(12.7)	0.4601	0.0019	4.21780	0.00320	0.01263	0.6056	0.0016	0.0025	1,272,827	G	2	384	2.6
340	08/13/84	78.76	709.81	2.2695	(12.8)	0.4604	0.0019	4.22142	0.00320	0.01262	0.6057	0.0016	0.0025	1,273,934	G	2	384	2.3
341	08/13/84	79.11	710.27	2.2691	(12.8)	0.4610	0.0019	4.22290	0.00321	0.01264	0.6056	0.0016	0.0025	1,273,752	G	2	385	2.6
342	08/13/84	78.51	710.77	2.2743	(12.8)	0.4609	0.0019	4.22854	0.00321	0.01263	0.6058	0.0016	0.0025	1,276,280	G	2	385	2.2
343	08/13/84	78.86	711.11	2.2735	(12.8)	0.4614	0.0019	4.23004	0.00321	0.01264	0.6058	0.0016	0.0025	1,276,131	G	2	385	2.3
630	09/26/84	89.07	711.28	2.2012	(12.9)	0.4648	0.0015	4.17435	0.00506	0.01301	0.6052	0.0015	0.0026	1,244,759	G	2	386	10.3
631	09/26/84	89.20	710.20	2.1969	(12.9)	0.4638	0.0014	4.16738	0.00506	0.01300	0.6055	0.0014	0.0026	1,242,682	G	2	385	10.5
632	09/26/84	89.29	711.05	2.1993	(12.8)	0.4626	0.0014	4.16298	0.00506	0.01300	0.6053	0.0014	0.0026	1,241,093	G	2	385	10.7
633	09/26/84	89.44	711.91	2.2013	(12.8)	0.4631	0.0014	4.15839	0.00505	0.01300	0.6040	0.0014	0.0026	1,239,332	G	2	384	10.9
634	09/26/84	86.84	713.21	2.2202	(23.1)	0.8339	0.0014	5.61768	0.00987	0.02662	0.6055	0.0015	0.0036	1,679,056	G	1	386	9.0
635	09/26/84	86.81	714.02	2.2231	(23.1)	0.8342	0.0014	5.62510	0.00988	0.02665	0.6057	0.0014	0.0036	1,681,130	G	1	386	8.9
636	09/26/84	86.75	714.49	2.2251	(23.1)	0.8349	0.0014	5.62960	0.00989	0.02666	0.6057	0.0014	0.0036	1,682,482	G	1	386	8.8
637	09/26/84	86.63	714.88	2.2270	(23.1)	0.8355	0.0014	5.63383	0.00988	0.02667	0.6057	0.0014	0.0036	1,683,890	G	1	387	8.7
638	09/26/84	82.86	715.78	2.2511	(52.2)	1.8826	0.0080	8.50107	0.01082	0.03524	0.6055	0.0017	0.0032	2,551,807	G	2	387	5.4
639	09/26/84	82.99	716.77	2.2537	(52.2)	1.8849	0.0081	8.51177	0.01083	0.03530	0.6055	0.0017	0.0032	2,554,224	G	2	388	5.5
640	09/26/84	82.96	717.59	2.2567	(52.3)	1.8868	0.0081	8.52254	0.01083	0.03534	0.6056	0.0017	0.0032	2,557,235	G	2	388	5.4
641	09/26/84	82.95	718.12	2.2586	(52.3)	1.8889	0.0080	8.52907	0.01083	0.03536	0.6054	0.0017	0.0032	2,559,031	G	2	389	5.4
644	09/26/84	80.02	721.27	2.2831	(92.7)	3.3460	0.0082	11.4279	0.02908	0.05350	0.6060	0.0019	0.0035	3,440,014	G	1	390	2.8
645	09/26/84	79.98	721.67	2.2848	(92.7)	3.3467	0.0081	11.4351	0.02908	0.05353	0.6061	0.0019	0.0035	3,442,144	G	1	391	2.8
646	09/26/84	79.93	721.81	2.2855	(92.7)	3.3467	0.0082	11.4379	0.02909	0.05354	0.6062	0.0019	0.0035	3,443,096	G	1	391	2.8
647	09/26/84	79.75	722.17	2.2864	(92.8)	3.3476	0.0082	11.4434	0.02910	0.05353	0.6063	0.0019	0.0035	3,445,729	G	1	391	2.6

Table 28F. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-4A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.4984 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.57724 (1984), 0.57163 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand.	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
								(pounds/second)									
648	09/26/84	77.28	720.64	2.2942	(145.1)	5.2359	0.0081	14.3356	0.02948	0.06179	0.6060	0.0016	0.0033	4,330,952	G 2	390	0.3
649	09/26/84	77.21	721.92	2.2988	(145.3)	5.2440	0.0081	14.3629	0.02953	0.06190	0.6060	0.0016	0.0033	4,338,947	G 2	391	0.2
650	09/26/84	77.12	722.59	2.3016	(145.4)	5.2479	0.0081	14.3784	0.02953	0.06194	0.6061	0.0016	0.0033	4,343,604	G 2	391	0.1
651	09/26/84	77.10	723.18	2.3038	(145.5)	5.2522	0.0082	14.3910	0.02954	0.06199	0.6061	0.0016	0.0033	4,347,109	G 2	392	0.1

Table 28G. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-4B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.4999 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.57748 (1984), 0.57188 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.		-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand. (pounds/second)	Syst.	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
206	08/06/84	82.52	657.74	2.0677	(11.8)	0.4253	0.0018	3.87798	0.00292	0.01182	0.6060	0.0016	0.0026	1,174,699	G	2	357	5.7
207	08/06/84	82.48	657.69	2.0677	(11.8)	0.4252	0.0018	3.87753	0.00292	0.01182	0.6060	0.0016	0.0026	1,174,628	G	2	356	5.7
208	08/06/84	81.80	657.70	2.0710	(11.8)	0.4250	0.0018	3.87956	0.00293	0.01180	0.6060	0.0016	0.0026	1,176,236	G	2	356	5.3
209	08/06/84	80.81	657.69	2.0761	(11.8)	0.4250	0.0018	3.88383	0.00293	0.01176	0.6059	0.0016	0.0026	1,178,985	G	2	356	4.5
210	08/06/84	80.80	657.66	2.0760	(11.8)	0.4254	0.0018	3.88461	0.00293	0.01175	0.6057	0.0016	0.0026	1,179,233	G	2	356	4.3
211	08/06/84	80.66	657.66	2.0767	(11.8)	0.4251	0.0018	3.88521	0.00293	0.01175	0.6059	0.0016	0.0026	1,179,623	G	2	356	4.2
212	08/06/84	79.27	656.95	2.0813	(21.2)	0.7661	0.0018	5.22379	0.00761	0.02428	0.6062	0.0015	0.0035	1,589,019	G	1	356	3.1
213	08/06/84	78.99	656.89	2.0826	(21.2)	0.7659	0.0018	5.22527	0.00762	0.02426	0.6062	0.0015	0.0035	1,590,012	G	1	356	2.8
214	08/06/84	78.92	656.86	2.0832	(21.2)	0.7660	0.0018	5.22613	0.00762	0.02426	0.6062	0.0015	0.0035	1,590,394	G	1	356	2.7
215	08/06/84	78.85	656.80	2.0834	(21.2)	0.7662	0.0018	5.22618	0.00762	0.02426	0.6061	0.0015	0.0035	1,590,567	G	1	356	2.7
216	08/06/84	78.77	656.76	2.0837	(21.2)	0.7660	0.0019	5.22606	0.00762	0.02425	0.6061	0.0015	0.0035	1,590,710	G	1	356	2.6
217	08/06/84	78.68	656.73	2.0840	(21.2)	0.7659	0.0019	5.22649	0.00762	0.02424	0.6062	0.0015	0.0035	1,591,016	G	1	356	2.5
509	10/01/85	79.60	562.88	1.7850	(204.4)	7.3760	0.0066	14.8976	0.02528	0.07054	0.6017	0.0015	0.0037	4,542,344	G	1	307	3.9
510	10/01/85	80.08	562.23	1.7807	(204.2)	7.3686	0.0067	14.8743	0.02525	0.07049	0.6018	0.0015	0.0037	4,532,800	G	1	307	4.2
511	10/01/85	80.43	561.83	1.7778	(204.0)	7.3643	0.0065	14.8564	0.02522	0.07048	0.6017	0.0015	0.0037	4,525,527	G	1	306	4.5
512	10/01/85	80.74	561.43	1.7752	(203.9)	7.3584	0.0067	14.8402	0.02520	0.07047	0.6018	0.0015	0.0037	4,518,979	G	1	306	4.8
638	10/25/85	91.12	635.63	1.9767	(11.8)	0.4250	0.0014	3.72319	0.00630	0.01183	0.5966	0.0018	0.0026	1,107,141	G	2	345	13.8
639	10/25/85	91.04	635.21	1.9760	(11.8)	0.4242	0.0014	3.72114	0.00630	0.01182	0.5969	0.0018	0.0026	1,106,695	G	2	345	13.7
640	10/25/85	91.09	634.92	1.9748	(11.8)	0.4242	0.0014	3.71917	0.00630	0.01182	0.5967	0.0018	0.0026	1,106,090	G	2	344	13.8
641	10/25/85	91.14	634.84	1.9741	(11.7)	0.4240	0.0014	3.71836	0.00630	0.01182	0.5969	0.0018	0.0026	1,105,804	G	2	344	13.8
642	10/25/85	90.92	632.50	1.9670	(47.3)	1.7087	0.0026	7.46703	0.01449	0.03201	0.5979	0.0017	0.0033	2,221,982	G	2	344	13.9
643	10/25/85	91.05	631.56	1.9632	(47.3)	1.7069	0.0026	7.45665	0.01451	0.03198	0.5980	0.0017	0.0033	2,218,829	G	2	343	13.9
644	10/25/85	90.85	630.00	1.9590	(47.2)	1.7022	0.0027	7.43683	0.01450	0.03188	0.5979	0.0017	0.0033	2,213,979	G	2	342	13.8
645	10/25/85	90.56	628.53	1.9550	(47.1)	1.6992	0.0028	7.41994	0.01449	0.03178	0.5977	0.0017	0.0033	2,210,259	G	2	342	13.6
646	10/25/85	86.87	623.08	1.9535	(103.4)	3.7330	0.0031	11.0427	0.02854	0.05096	0.6000	0.0020	0.0035	3,307,438	G	2	339	10.2
647	10/25/85	87.77	622.23	1.9464	(102.9)	3.7152	0.0032	11.0132	0.02848	0.05099	0.6009	0.0020	0.0035	3,295,248	G	2	338	11.1
648	10/25/85	87.66	621.76	1.9453	(102.8)	3.7110	0.0031	11.0050	0.02847	0.05094	0.6010	0.0020	0.0035	3,293,471	G	2	338	11.0
649	10/25/85	87.80	621.53	1.9433	(102.8)	3.7102	0.0030	10.9976	0.02846	0.05092	0.6009	0.0020	0.0035	3,290,857	G	2	338	11.1
650	10/25/85	84.95	618.54	1.9454	(153.1)	5.5266	0.0035	13.4376	0.02907	0.05810	0.6010	0.0018	0.0034	4,037,599	G	3	337	8.6
651	10/25/85	85.12	618.79	1.9455	(153.2)	5.5281	0.0036	13.4407	0.02907	0.05815	0.6010	0.0018	0.0034	4,037,548	G	3	337	8.7
652	10/25/85	84.92	619.04	1.9472	(153.2)	5.5309	0.0033	13.4495	0.02908	0.05815	0.6010	0.0018	0.0034	4,041,029	G	3	337	8.6
653	10/25/85	84.85	619.01	1.9475	(153.2)	5.5297	0.0034	13.4501	0.02908	0.05814	0.6011	0.0018	0.0034	4,041,611	G	3	337	8.5

Table 28G. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-4B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.4999 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.57748 (1984), 0.57188 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Coefficient Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
654	10/25/85	81.31	615.89	1.9530	(224.4)	8.1001	0.0040	16.3049	0.03924	0.07746	0.6008	0.0019	0.0036	4,924,066	G 1	336	5.3
655	10/25/85	81.36	615.74	1.9522	(224.4)	8.0990	0.0039	16.3003	0.03924	0.07745	0.6007	0.0019	0.0036	4,922,460	G 1	336	5.3
656	10/25/85	81.42	615.99	1.9528	(224.5)	8.1018	0.0039	16.3066	0.03924	0.07749	0.6008	0.0019	0.0036	4,923,796	G 1	336	5.3
657	10/25/85	81.45	616.09	1.9529	(224.5)	8.1042	0.0038	16.3088	0.03924	0.07751	0.6007	0.0019	0.0036	4,924,204	G 1	336	5.4

Table 28H. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-5A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.9997 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.65995 (1984), 0.65355 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.		-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
37	07/09/84	86.15	525.32	1.6906	(9.0)	0.3236	0.0023	4.19198	0.00581	0.02011	0.6071	0.0025	0.0038	1,280,535	A	1	286	11.6
38	07/09/84	85.72	524.25	1.6886	(9.0)	0.3230	0.0022	4.18501	0.00581	0.02005	0.6070	0.0025	0.0038	1,279,323	A	1	285	11.2
40	07/09/84	85.04	522.00	1.6835	(8.9)	0.3213	0.0023	4.16948	0.00580	0.01994	0.6073	0.0025	0.0038	1,276,128	A	1	284	10.6
41	07/09/84	82.50	628.50	1.9780	(10.8)	0.3910	0.0022	4.97487	0.00625	0.02340	0.6061	0.0021	0.0036	1,513,808	G	1	341	6.5
42	07/09/84	82.62	627.56	1.9736	(10.8)	0.3899	0.0022	4.96629	0.00625	0.02337	0.6065	0.0021	0.0036	1,511,150	G	1	341	6.5
43	07/09/84	82.82	626.74	1.9699	(10.8)	0.3896	0.0022	4.95821	0.00624	0.02334	0.6064	0.0021	0.0036	1,508,484	G	1	340	6.7
44	07/09/84	82.84	626.06	1.9675	(10.8)	0.3893	0.0022	4.95267	0.00623	0.02332	0.6062	0.0021	0.0036	1,506,916	G	1	340	6.7
45	07/09/84	82.89	625.40	1.9650	(10.8)	0.3886	0.0022	4.94687	0.00623	0.02330	0.6065	0.0021	0.0036	1,505,206	G	1	339	6.8
46	07/13/84	85.66	658.03	2.0576	(11.3)	0.4088	0.0018	5.19377	0.00826	0.02463	0.6066	0.0019	0.0036	1,566,329	G	1	357	9.0
47	07/13/84	84.89	658.39	2.0617	(11.3)	0.4089	0.0018	5.20038	0.00826	0.02461	0.6067	0.0019	0.0036	1,569,848	G	1	357	8.3
48	07/13/84	84.49	658.69	2.0659	(11.3)	0.4090	0.0018	5.20695	0.00827	0.02461	0.6069	0.0019	0.0036	1,572,457	G	1	357	8.0
49	07/13/84	84.03	658.99	2.0692	(11.3)	0.4093	0.0018	5.21236	0.00827	0.02460	0.6067	0.0019	0.0036	1,574,921	G	1	357	7.6
50	07/13/84	83.88	659.20	2.0706	(11.3)	0.4093	0.0018	5.21558	0.00827	0.02460	0.6069	0.0019	0.0036	1,576,126	G	1	358	7.3
51	07/13/84	83.74	659.37	2.0720	(11.3)	0.4096	0.0018	5.21766	0.00828	0.02460	0.6068	0.0019	0.0036	1,577,012	G	1	358	7.3
65	07/18/84	81.49	698.41	2.2199	(27.2)	0.9800	0.0022	8.34679	0.00812	0.03452	0.6062	0.0012	0.0032	2,515,184	G	2	379	4.7
66	07/18/84	81.33	698.58	2.2210	(27.2)	0.9800	0.0022	8.34957	0.00812	0.03451	0.6063	0.0012	0.0032	2,516,482	G	2	379	4.6
67	07/18/84	80.61	698.76	2.2257	(27.2)	0.9803	0.0022	8.35900	0.00813	0.03447	0.6062	0.0012	0.0032	2,521,492	G	2	379	4.0
68	07/18/84	80.32	698.93	2.2279	(27.2)	0.9805	0.0022	8.36440	0.00813	0.03446	0.6062	0.0012	0.0032	2,523,927	G	2	379	3.7
69	07/18/84	79.90	699.11	2.2309	(27.2)	0.9814	0.0022	8.37135	0.00814	0.03443	0.6061	0.0012	0.0032	2,527,259	G	2	379	3.3
70	07/18/84	79.91	699.30	2.2316	(27.2)	0.9816	0.0022	8.37423	0.00814	0.03444	0.6061	0.0012	0.0032	2,528,033	G	2	379	3.3
85	07/23/84	84.53	662.75	2.0786	(25.7)	0.9289	0.0016	7.86366	0.00873	0.03291	0.6062	0.0012	0.0033	2,373,020	G	2	360	7.6
86	07/23/84	84.49	661.63	2.0750	(25.7)	0.9271	0.0016	7.85065	0.00873	0.03285	0.6063	0.0013	0.0033	2,369,601	G	2	359	7.6
87	07/23/84	84.09	660.55	2.0736	(25.6)	0.9254	0.0016	7.84133	0.00872	0.03278	0.6064	0.0013	0.0033	2,368,358	G	2	359	7.3
88	07/23/84	83.82	659.54	2.0715	(25.6)	0.9238	0.0016	7.83210	0.00872	0.03271	0.6065	0.0013	0.0033	2,366,623	G	2	358	7.1
89	07/23/84	83.66	658.98	2.0705	(25.6)	0.9233	0.0015	7.82704	0.00872	0.03267	0.6064	0.0013	0.0033	2,365,778	G	2	358	6.9
90	07/23/84	83.70	658.28	2.0679	(25.6)	0.9227	0.0017	7.81841	0.00871	0.03264	0.6063	0.0013	0.0033	2,363,281	G	2	357	7.0
91	07/23/84	86.15	658.85	2.0561	(11.4)	0.4111	0.0014	5.20144	0.00812	0.02469	0.6061	0.0017	0.0036	1,567,365	G	1	358	9.2
92	07/23/84	85.91	658.45	2.0557	(11.4)	0.4110	0.0014	5.19893	0.00813	0.02467	0.6059	0.0017	0.0036	1,567,207	G	1	357	9.1
93	07/23/84	85.41	658.09	2.0566	(11.4)	0.4102	0.0015	5.19826	0.00813	0.02463	0.6063	0.0017	0.0036	1,568,162	G	1	357	8.7
94	07/23/84	84.83	657.68	2.0582	(11.4)	0.4100	0.0014	5.19846	0.00813	0.02459	0.6062	0.0017	0.0036	1,569,457	G	1	357	8.2
95	07/23/84	84.44	657.26	2.0587	(11.3)	0.4094	0.0015	5.19777	0.00813	0.02455	0.6065	0.0017	0.0036	1,570,102	G	1	357	7.8
96	07/23/84	84.34	656.73	2.0575	(11.3)	0.4093	0.0015	5.19408	0.00814	0.02453	0.6063	0.0017	0.0036	1,569,296	G	1	356	7.7

Table 28H. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-5A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 3.9997 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.65995 (1984), 0.65355 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand. (pounds/second)	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
98	07/25/84	88.55	613.61	1.8932	(10.5)	0.3784	0.0022	4.81029	0.00744	0.02303	0.6088	0.0022	0.0037	1,455,106	G 1	333	11.6
99	07/25/84	88.46	613.21	1.8923	(10.5)	0.3784	0.0022	4.80751	0.00744	0.02302	0.6086	0.0022	0.0037	1,454,505	G 1	333	11.5
100	07/25/84	88.17	613.00	1.8929	(10.5)	0.3780	0.0022	4.80717	0.00744	0.02300	0.6088	0.0022	0.0037	1,454,977	G 1	333	11.4
101	07/25/84	88.06	611.77	1.8877	(10.5)	0.3774	0.0021	4.79647	0.00743	0.02293	0.6088	0.0022	0.0037	1,452,469	G 1	332	11.1
102	07/25/84	88.07	611.49	1.8867	(10.5)	0.3773	0.0021	4.79413	0.00743	0.02292	0.6087	0.0022	0.0037	1,451,793	G 1	332	11.2
103	07/25/84	87.99	611.11	1.8858	(10.5)	0.3773	0.0021	4.79124	0.00743	0.02290	0.6084	0.0022	0.0037	1,451,146	G 1	332	11.1
104	07/25/84	88.23	607.92	1.8736	(23.4)	0.8459	0.0022	7.14318	0.00797	0.03034	0.6077	0.0015	0.0034	2,163,814	G 2	330	11.3
105	07/25/84	88.01	607.74	1.8742	(23.4)	0.8454	0.0022	7.14313	0.00797	0.03032	0.6078	0.0015	0.0034	2,164,462	G 2	330	11.1
106	07/25/84	87.92	607.66	1.8744	(23.4)	0.8455	0.0022	7.14294	0.00797	0.03031	0.6077	0.0015	0.0034	2,164,672	G 2	330	11.0
107	07/25/84	87.88	607.58	1.8743	(23.4)	0.8453	0.0022	7.14212	0.00797	0.03031	0.6078	0.0015	0.0034	2,164,554	G 2	330	11.0
108	07/25/84	87.65	607.90	1.8764	(23.4)	0.8457	0.0022	7.14800	0.00798	0.03031	0.6078	0.0015	0.0034	2,166,858	G 2	330	10.8
109	07/25/84	87.55	608.13	1.8776	(23.4)	0.8461	0.0021	7.15176	0.00798	0.03031	0.6077	0.0015	0.0034	2,168,214	G 2	330	10.7
672	09/28/84	90.38	609.80	1.8525	(10.6)	0.3820	0.0019	4.75130	0.00858	0.02281	0.6050	0.0021	0.0037	1,436,270	G 1	331	12.4
673	09/28/84	90.43	608.76	1.8488	(10.6)	0.3810	0.0020	4.74230	0.00856	0.02278	0.6052	0.0022	0.0037	1,433,657	G 1	330	12.5
674	09/28/84	90.61	607.59	1.8443	(10.5)	0.3796	0.0019	4.73218	0.00857	0.02275	0.6059	0.0022	0.0037	1,430,506	G 1	330	12.7
675	09/28/84	90.65	606.59	1.8423	(10.5)	0.3791	0.0020	4.72545	0.00856	0.02272	0.6057	0.0022	0.0037	1,428,394	G 1	329	12.8
676	09/28/84	87.78	599.63	1.8330	(23.3)	0.8415	0.0019	7.02670	0.00935	0.02976	0.6060	0.0015	0.0034	2,133,591	G 2	326	10.5
677	09/28/84	87.79	598.12	1.8286	(23.3)	0.8391	0.0019	7.00931	0.00940	0.02969	0.6061	0.0015	0.0034	2,128,596	G 2	325	10.5
678	09/28/84	87.79	595.38	1.8196	(23.1)	0.8350	0.0018	6.97636	0.00940	0.02956	0.6062	0.0015	0.0034	2,119,390	G 2	323	10.5
679	09/28/84	87.87	592.72	1.8105	(23.0)	0.8313	0.0018	6.94324	0.00932	0.02943	0.6062	0.0015	0.0034	2,109,883	G 2	322	10.6
680	09/28/84	84.77	586.60	1.8052	(40.3)	1.4533	0.0078	9.17672	0.02330	0.04383	0.6068	0.0025	0.0037	2,801,582	G 1	319	8.0
681	09/28/84	84.87	585.08	1.7997	(40.1)	1.4484	0.0078	9.15111	0.02325	0.04372	0.6070	0.0025	0.0037	2,794,002	G 1	318	8.1
682	09/28/84	84.89	584.11	1.7965	(40.0)	1.4454	0.0078	9.13531	0.02321	0.04365	0.6072	0.0025	0.0037	2,789,489	G 1	318	8.2
683	09/28/84	84.81	583.35	1.7943	(40.0)	1.4439	0.0078	9.12334	0.02319	0.04359	0.6070	0.0025	0.0037	2,786,399	G 1	317	8.1
684	09/28/84	80.02	577.25	1.7958	(89.4)	3.2251	0.0082	13.6527	0.02475	0.06411	0.6073	0.0018	0.0037	4,198,468	G 2	314	3.9
685	09/28/84	80.18	577.85	1.7970	(89.5)	3.2293	0.0080	13.6648	0.02474	0.06420	0.6072	0.0018	0.0037	4,200,947	G 2	314	4.0
686	09/28/84	80.27	578.17	1.7977	(89.5)	3.2307	0.0080	13.6714	0.02474	0.06425	0.6073	0.0018	0.0037	4,202,291	G 2	315	4.1
687	09/28/84	80.25	578.53	1.7990	(89.5)	3.2307	0.0080	13.6797	0.02475	0.06428	0.6074	0.0018	0.0037	4,204,704	G 2	315	4.1
688	09/28/84	77.22	569.64	1.7828	(137.8)	4.9721	0.0081	16.8951	0.02518	0.07306	0.6072	0.0015	0.0035	5,220,033	G 4	310	1.4
689	09/28/84	77.21	567.77	1.7765	(137.3)	4.9550	0.0080	16.8376	0.02509	0.07281	0.6072	0.0015	0.0035	5,203,741	G 4	309	1.4
690	09/28/84	77.20	566.70	1.7730	(137.0)	4.9459	0.0080	16.8050	0.02501	0.07267	0.6072	0.0015	0.0035	5,194,533	G 4	309	1.3
691	09/28/84	77.27	566.06	1.7705	(136.9)	4.9416	0.0082	16.7834	0.02499	0.07259	0.6071	0.0016	0.0035	5,187,872	G 4	308	1.4

Table 28I. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-5B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 4.0002 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.66003 (1984), 0.65363 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
110	07/26/84	89.36	647.14	1.9963	(11.1)	0.4013	0.0010	5.07812	0.00658	0.02432	0.6076	0.0014	0.0037	1,527,446	G 1	351	11.8
111	07/26/84	89.68	647.23	1.9951	(11.1)	0.4013	0.0010	5.07709	0.00658	0.02433	0.6076	0.0014	0.0037	1,526,513	G 1	351	12.1
112	07/26/84	89.80	647.28	1.9947	(11.1)	0.4015	0.0010	5.07673	0.00658	0.02434	0.6075	0.0014	0.0037	1,526,156	G 1	351	12.2
113	07/26/84	90.06	647.31	1.9932	(11.1)	0.4016	0.0010	5.07508	0.00657	0.02435	0.6074	0.0014	0.0037	1,525,202	G 1	351	12.4
114	07/26/84	90.30	647.28	1.9920	(11.1)	0.4017	0.0010	5.07346	0.00657	0.02436	0.6074	0.0014	0.0037	1,524,275	G 1	351	12.6
115	07/26/84	90.95	647.14	1.9884	(11.1)	0.4019	0.0010	5.06936	0.00658	0.02438	0.6073	0.0014	0.0037	1,521,838	G 1	351	13.1
116	07/26/84	89.55	644.67	1.9868	(24.9)	0.9001	0.0012	7.58311	0.00702	0.03227	0.6072	0.0012	0.0033	2,281,274	G 2	350	12.0
117	07/26/84	89.45	644.14	1.9857	(24.9)	0.8989	0.0012	7.57738	0.00702	0.03224	0.6073	0.0012	0.0033	2,280,001	G 2	350	11.9
118	07/26/84	89.15	643.72	1.9856	(24.9)	0.8987	0.0012	7.57391	0.00702	0.03220	0.6071	0.0012	0.0033	2,279,987	G 2	349	11.7
119	07/26/84	89.15	643.15	1.9837	(24.9)	0.8979	0.0012	7.56764	0.00702	0.03216	0.6072	0.0012	0.0033	2,278,261	G 2	349	11.6
120	07/26/84	89.11	642.64	1.9821	(24.9)	0.8973	0.0012	7.56086	0.00701	0.03214	0.6071	0.0012	0.0033	2,276,500	G 2	349	11.6
121	07/26/84	88.95	642.08	1.9811	(24.8)	0.8963	0.0012	7.55548	0.00701	0.03210	0.6071	0.0012	0.0033	2,275,522	G 2	348	11.5
618	10/24/85	90.58	724.89	2.2729	(12.9)	0.4656	0.0012	5.73838	0.01256	0.02751	0.6000	0.0018	0.0036	1,686,392	G 1	393	12.5
619	10/24/85	90.64	724.61	2.2716	(12.9)	0.4654	0.0012	5.73584	0.01256	0.02750	0.6001	0.0018	0.0036	1,685,585	G 1	393	12.5
620	10/24/85	90.40	723.44	2.2689	(12.9)	0.4647	0.0012	5.72752	0.01256	0.02745	0.5999	0.0018	0.0036	1,683,912	G 1	392	12.4
621	10/24/85	90.67	723.17	2.2665	(12.9)	0.4643	0.0012	5.72327	0.01255	0.02745	0.6001	0.0018	0.0036	1,682,229	G 1	392	12.6
622	10/24/85	87.12	717.06	2.2655	(50.7)	1.8280	0.0029	11.3626	0.02771	0.05445	0.6004	0.0018	0.0036	3,357,019	G 1	389	9.7
623	10/24/85	87.26	716.46	2.2627	(50.6)	1.8255	0.0029	11.3501	0.02769	0.05442	0.6006	0.0018	0.0036	3,353,060	G 1	389	9.9
624	10/24/85	87.39	715.83	2.2598	(50.6)	1.8246	0.0028	11.3381	0.02767	0.05438	0.6004	0.0018	0.0036	3,349,343	G 1	389	10.0
625	10/24/85	87.49	715.23	2.2574	(50.5)	1.8224	0.0029	11.3267	0.02765	0.05435	0.6005	0.0018	0.0036	3,345,865	G 1	388	10.1
626	10/24/85	80.41	708.86	2.2757	(113.3)	4.0882	0.0036	17.0246	0.03051	0.07974	0.5999	0.0015	0.0035	5,077,053	G 2	385	3.8
627	10/24/85	80.35	708.86	2.2761	(113.3)	4.0886	0.0036	17.0262	0.03052	0.07972	0.5999	0.0015	0.0035	5,077,910	G 2	385	3.7
628	10/24/85	80.34	709.08	2.2768	(113.3)	4.0907	0.0037	17.0327	0.03052	0.07975	0.5999	0.0015	0.0035	5,079,705	G 2	385	3.7
629	10/24/85	80.37	709.42	2.2779	(113.4)	4.0937	0.0034	17.0409	0.03053	0.07979	0.5998	0.0015	0.0035	5,081,751	G 2	386	3.7
630	10/24/85	77.43	707.74	2.2894	(154.3)	5.5700	0.0043	19.9297	0.03100	0.08781	0.5997	0.0014	0.0033	5,965,945	G 3	385	1.1
631	10/24/85	77.39	707.95	2.2903	(154.3)	5.5682	0.0038	19.9363	0.03101	0.08783	0.5999	0.0014	0.0033	5,968,036	G 3	385	1.0
632	10/24/85	77.36	708.14	2.2911	(154.3)	5.5671	0.0155	19.9422	0.03102	0.08784	0.6000	0.0016	0.0033	5,969,819	G 3	385	1.0
633	10/24/85	77.29	708.32	2.2922	(154.4)	5.5724	0.0039	19.9487	0.03102	0.08785	0.5998	0.0014	0.0033	5,972,109	G 3	385	0.9
634	10/24/85	74.63	707.46	2.3053	(184.5)	6.6604	0.0042	21.8629	0.04161	0.09656	0.5994	0.0015	0.0033	6,567,259	G 2	385	-1.5
635	10/24/85	74.81	707.52	2.3044	(184.5)	6.6591	0.0043	21.8638	0.04161	0.09662	0.5996	0.0015	0.0033	6,565,978	G 2	385	-1.3
636	10/24/85	74.93	707.55	2.3037	(184.5)	6.6590	0.0044	21.8574	0.04160	0.09663	0.5995	0.0015	0.0033	6,563,070	G 2	385	-1.2
637	10/24/85	75.04	707.61	2.3033	(184.5)	6.6594	0.0042	21.8571	0.04159	0.09666	0.5995	0.0015	0.0033	6,562,085	G 2	385	-1.1

Table 28J. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-6A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 4.4992 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.74237 (1984), 0.73516 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
1	07/03/84	84.39	634.56	1.9878	(23.3)	0.8419	0.0015	9.99787	0.01943	0.04766	0.6065	0.0016	0.0037	3,032,856	G 1	345	7.8
2	07/03/84	84.64	634.63	1.9868	(23.3)	0.8419	0.0015	9.99593	0.01943	0.04769	0.6065	0.0016	0.0037	3,031,300	G 1	345	8.0
3	07/03/84	84.70	634.74	1.9867	(23.3)	0.8419	0.0015	9.99593	0.01943	0.04770	0.6065	0.0016	0.0037	3,031,056	G 1	345	8.1
4	07/03/84	84.50	635.02	1.9885	(23.3)	0.8423	0.0015	10.0097	0.01945	0.04765	0.6069	0.0016	0.0037	3,035,842	G 1	345	7.3
5	07/03/84	84.66	635.25	1.9886	(23.3)	0.8425	0.0016	10.0129	0.01946	0.04768	0.6070	0.0016	0.0037	3,036,125	G 1	345	7.4
6	07/03/84	84.78	635.27	1.9882	(23.4)	0.8432	0.0015	10.0129	0.01946	0.04769	0.6069	0.0016	0.0037	3,035,653	G 1	345	7.5
7	07/05/84	83.00	708.28	2.2515	(14.9)	0.5362	0.0011	8.46298	0.00883	0.03518	0.6045	0.0012	0.0032	2,542,776	G 2	384	6.1
8	07/05/84	82.65	707.25	2.2498	(14.8)	0.5352	0.0011	8.45368	0.00882	0.03510	0.6046	0.0012	0.0032	2,541,433	G 2	384	5.8
9	07/05/84	82.39	706.17	2.2475	(14.8)	0.5345	0.0011	8.44297	0.00882	0.03502	0.6045	0.0012	0.0032	2,539,450	G 2	383	5.5
10	07/05/84	82.41	705.13	2.2438	(14.8)	0.5338	0.0010	8.43060	0.00882	0.03497	0.6046	0.0012	0.0032	2,536,081	G 2	383	5.5
11	07/05/84	82.55	704.13	2.2395	(14.8)	0.5331	0.0010	8.41658	0.00881	0.03492	0.6045	0.0012	0.0032	2,531,779	G 2	382	5.6
12	07/05/84	82.80	703.05	2.2343	(14.7)	0.5320	0.0010	8.40068	0.00880	0.03489	0.6047	0.0012	0.0032	2,526,648	G 2	382	5.8
692	10/01/84	88.54	629.07	1.9443	(9.1)	0.3301	0.0014	6.15175	0.01218	0.02735	0.6026	0.0020	0.0035	1,857,488	G 2	341	11.4
693	10/01/84	88.40	629.14	1.9452	(9.1)	0.3301	0.0013	6.15381	0.01218	0.02735	0.6027	0.0020	0.0035	1,858,421	G 2	341	11.3
694	10/01/84	88.52	628.91	1.9439	(9.1)	0.3297	0.0013	6.15131	0.01218	0.02735	0.6030	0.0020	0.0035	1,857,435	G 2	341	11.3
695	10/01/84	88.32	628.81	1.9445	(9.1)	0.3296	0.0013	6.15141	0.01218	0.02734	0.6030	0.0020	0.0035	1,857,970	G 2	341	11.2
696	10/01/84	85.06	626.73	1.9458	(17.9)	0.6449	0.0014	8.61133	0.01318	0.03473	0.6033	0.0015	0.0032	2,613,174	G 3	340	8.2
697	10/01/84	85.25	626.70	1.9448	(17.9)	0.6450	0.0015	8.60987	0.01318	0.03474	0.6033	0.0015	0.0032	2,612,090	G 3	340	8.4
698	10/01/84	85.26	625.96	1.9423	(17.8)	0.6441	0.0015	8.59929	0.01317	0.03470	0.6033	0.0015	0.0032	2,609,157	G 3	340	8.4
699	10/01/84	85.37	625.74	1.9407	(17.9)	0.6442	0.0014	8.59448	0.01317	0.03469	0.6032	0.0015	0.0032	2,607,654	G 3	340	8.5
700	10/01/84	79.14	622.65	1.9599	(52.3)	1.8869	0.0082	14.8064	0.03361	0.06925	0.6041	0.0021	0.0036	4,530,310	G 2	339	3.0
701	10/01/84	79.04	623.00	1.9610	(52.3)	1.8878	0.0082	14.8154	0.03362	0.06927	0.6042	0.0021	0.0036	4,533,579	G 2	339	2.9
702	10/01/84	79.07	623.64	1.9631	(52.4)	1.8901	0.0082	14.8310	0.03363	0.06934	0.6041	0.0021	0.0036	4,537,791	G 2	339	2.9
703	10/01/84	79.02	623.30	1.9622	(52.3)	1.8890	0.0083	14.8238	0.03362	0.06930	0.6042	0.0022	0.0036	4,536,082	G 2	339	2.8
704	10/03/84	71.74	604.13	1.9314	(105.8)	3.8200	0.0081	20.9026	0.03890	0.09601	0.6036	0.0016	0.0036	6,478,219	G 2	329	-3.7
705	10/03/84	72.04	603.49	1.9278	(105.7)	3.8159	0.0083	20.8710	0.03888	0.09596	0.6036	0.0016	0.0036	6,466,604	G 2	328	-3.4
706	10/03/84	72.26	602.87	1.9246	(105.6)	3.8123	0.0081	20.8425	0.03885	0.09590	0.6035	0.0016	0.0036	6,456,475	G 2	328	-3.2
707	10/03/84	72.47	602.28	1.9215	(105.5)	3.8090	0.0082	20.8150	0.03882	0.09585	0.6035	0.0016	0.0036	6,446,791	G 2	328	-3.0
708	10/03/84	70.51	589.99	1.8886	(156.6)	5.6514	0.0080	25.1674	0.04475	0.11543	0.6040	0.0015	0.0036	7,829,205	G 2	322	-4.6
709	10/03/84	70.56	589.15	1.8855	(156.4)	5.6445	0.0078	25.1282	0.04473	0.11527	0.6039	0.0015	0.0036	7,817,535	G 2	321	-4.6
710	10/03/84	70.61	588.30	1.8823	(156.2)	5.6374	0.0080	25.0892	0.04470	0.11511	0.6039	0.0015	0.0036	7,805,867	G 2	321	-4.5
711	10/03/84	70.67	587.43	1.8790	(156.0)	5.6284	0.0079	25.0498	0.04466	0.11496	0.6039	0.0015	0.0036	7,794,069	G 2	320	-4.5

Table 28J. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-6A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 4.4992 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.74237 (1984), 0.73516 (1985)

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
606	10/22/85	81.11	701.54	2.2423	(61.3)	2.2134	0.0043	16.7973	0.02572	0.07884	0.5965	0.0014	0.0035	5,012,458	G 2	381	4.4
607	10/22/85	81.11	701.64	2.2427	(61.3)	2.2130	0.0042	16.8007	0.02573	0.07885	0.5966	0.0014	0.0035	5,013,398	G 2	381	4.4
608	10/22/85	81.15	701.74	2.2428	(61.3)	2.2134	0.0041	16.8026	0.02573	0.07887	0.5966	0.0014	0.0035	5,013,634	G 2	381	4.4
609	10/22/85	81.16	701.83	2.2433	(61.4)	2.2146	0.0043	16.8054	0.02573	0.07889	0.5965	0.0014	0.0035	5,014,316	G 2	381	4.4
610	10/22/85	74.46	695.09	2.2583	(126.9)	4.5817	0.0050	24.2449	0.03311	0.11201	0.5960	0.0012	0.0034	7,301,243	G 2	378	-1.6
611	10/22/85	74.26	695.10	2.2597	(126.9)	4.5811	0.0047	24.2526	0.03312	0.11198	0.5961	0.0012	0.0034	7,305,463	G 2	378	-1.8
612	10/22/85	74.09	694.70	2.2592	(126.8)	4.5778	0.0051	24.2434	0.03323	0.11187	0.5961	0.0012	0.0034	7,304,614	G 2	378	-1.9
613	10/22/85	73.94	692.68	2.2529	(126.5)	4.5648	0.0051	24.1743	0.03318	0.11151	0.5961	0.0012	0.0034	7,287,549	G 2	377	-2.1
614	10/22/85	70.64	676.53	2.2144	(187.0)	6.7485	0.0058	29.1802	0.03920	0.13349	0.5967	0.0012	0.0034	8,855,214	G 2	369	-4.9
615	10/22/85	70.58	675.46	2.2110	(186.8)	6.7403	0.0057	29.1341	0.03918	0.13325	0.5965	0.0012	0.0034	8,843,504	G 2	368	-5.0
616	10/22/85	70.56	674.67	2.2082	(186.4)	6.7291	0.0059	29.1044	0.03913	0.13311	0.5968	0.0012	0.0034	8,835,816	G 2	368	-5.0
617	10/22/85	70.54	674.08	2.2062	(186.4)	6.7259	0.0055	29.0791	0.03911	0.13299	0.5967	0.0012	0.0034	8,829,153	G 2	367	-5.0

Table 28K. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-6B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 4.4997 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.74245 (1984), 0.73525 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/	Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand. (pounds/second)	Syst.	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
140	07/31/84	86.29	663.50	2.0758	(13.8)	0.4980	0.0020	7.86130	0.00826	0.03310	0.6066	0.0016	0.0033	2,365,927	G	2	360	9.2
141	07/31/84	85.90	663.35	2.0771	(13.8)	0.4983	0.0019	7.86352	0.00826	0.03307	0.6064	0.0016	0.0033	2,367,777	G	2	360	8.9
142	07/31/84	85.59	663.19	2.0783	(13.8)	0.4980	0.0019	7.86527	0.00827	0.03304	0.6065	0.0016	0.0033	2,369,256	G	2	360	8.6
143	07/31/84	85.49	662.99	2.0782	(13.8)	0.4984	0.0019	7.86474	0.00827	0.03302	0.6063	0.0016	0.0033	2,369,474	G	2	360	8.5
144	07/31/84	85.42	662.80	2.0779	(13.8)	0.4981	0.0019	7.86343	0.00827	0.03301	0.6064	0.0016	0.0033	2,369,350	G	2	360	8.4
145	07/31/84	85.33	662.61	2.0776	(13.8)	0.4978	0.0019	7.86244	0.00827	0.03300	0.6065	0.0016	0.0033	2,369,364	G	2	360	8.4
146	07/31/84	83.21	660.35	2.0808	(24.3)	0.8765	0.0020	10.4524	0.02275	0.04961	0.6072	0.0018	0.0036	3,159,149	G	1	359	6.6
147	07/31/84	83.01	660.12	2.0811	(24.3)	0.8759	0.0020	10.4516	0.02275	0.04957	0.6073	0.0018	0.0036	3,159,839	G	1	359	6.4
148	07/31/84	83.03	659.89	2.0802	(24.3)	0.8758	0.0020	10.4489	0.02274	0.04956	0.6073	0.0018	0.0036	3,158,971	G	1	359	6.4
149	07/31/84	83.11	659.63	2.0789	(24.2)	0.8749	0.0020	10.4443	0.02273	0.04955	0.6075	0.0018	0.0036	3,157,397	G	1	359	6.4
150	07/31/84	83.04	659.31	2.0782	(24.2)	0.8745	0.0020	10.4402	0.02273	0.04952	0.6075	0.0018	0.0036	3,156,592	G	1	358	6.4
151	07/31/84	83.26	658.98	2.0758	(24.2)	0.8751	0.0021	10.4324	0.02271	0.04951	0.6072	0.0018	0.0036	3,153,579	G	1	358	6.6
529	10/08/85	69.10	730.84	2.4234	(202.4)	7.3044	0.0084	31.7612	0.04483	0.14425	0.5965	0.0012	0.0034	9,571,638	G	2	398	-6.7
530	10/08/85	69.36	730.05	2.4186	(202.2)	7.2963	0.0080	31.7077	0.04478	0.14413	0.5964	0.0012	0.0034	9,553,672	G	2	398	-6.5
531	10/08/85	69.51	729.45	2.4154	(202.0)	7.2890	0.0084	31.6737	0.04474	0.14406	0.5965	0.0012	0.0034	9,542,651	G	2	397	-6.3
532	10/08/85	69.62	728.91	2.4127	(201.8)	7.2837	0.0084	31.6431	0.04471	0.14397	0.5964	0.0012	0.0034	9,533,075	G	2	397	-6.2
533	10/08/85	76.63	732.07	2.3797	(78.7)	2.8414	0.0074	19.6096	0.03645	0.09136	0.5964	0.0016	0.0034	5,854,664	G	1	398	0.1
534	10/08/85	76.66	731.50	2.3775	(78.6)	2.8376	0.0073	19.5928	0.03643	0.09129	0.5965	0.0016	0.0034	5,850,046	G	1	397	0.1
535	10/08/85	76.80	731.01	2.3748	(78.6)	2.8360	0.0073	19.5747	0.03640	0.09125	0.5965	0.0016	0.0034	5,844,088	G	1	397	0.2
536	10/08/85	76.94	730.31	2.3715	(78.5)	2.8324	0.0074	19.5517	0.03638	0.09119	0.5966	0.0016	0.0034	5,836,912	G	1	397	0.4
537	10/10/85	70.17	657.44	2.1562	(181.6)	6.5532	0.0077	28.3748	0.05380	0.12974	0.5965	0.0017	0.0034	8,645,576	G	2	359	-5.1
538	10/10/85	70.39	656.15	2.1503	(181.2)	6.5414	0.0077	28.3091	0.05375	0.12954	0.5964	0.0017	0.0034	8,624,898	G	2	358	-4.9
539	10/10/85	70.56	654.17	2.1423	(180.7)	6.5233	0.0081	28.2118	0.05403	0.12918	0.5963	0.0017	0.0034	8,596,141	G	2	357	-4.8
540	10/10/85	70.66	650.80	2.1297	(179.7)	6.4864	0.0075	28.0527	0.05364	0.12851	0.5964	0.0017	0.0034	8,551,210	G	2	355	-4.6
598	10/21/85	80.45	683.45	2.1839	(59.7)	2.1553	0.0048	16.3592	0.02998	0.07667	0.5963	0.0016	0.0035	4,898,607	G	2	371	3.9
599	10/21/85	80.67	683.47	2.1828	(59.7)	2.1550	0.0049	16.3548	0.02997	0.07671	0.5964	0.0016	0.0035	4,895,955	G	2	371	4.1
600	10/21/85	80.84	683.25	2.1811	(59.7)	2.1540	0.0048	16.3456	0.02995	0.07671	0.5964	0.0016	0.0035	4,892,315	G	2	371	4.3
601	10/21/85	80.98	683.08	2.1798	(59.6)	2.1523	0.0048	16.3381	0.02994	0.07671	0.5965	0.0016	0.0035	4,889,298	G	2	371	4.4
602	10/21/85	74.50	676.03	2.1912	(123.2)	4.4477	0.0052	23.5441	0.03833	0.10888	0.5962	0.0014	0.0035	7,110,355	G	2	368	-1.4
603	10/21/85	74.33	675.15	2.1891	(123.1)	4.4413	0.0055	23.5177	0.03830	0.10870	0.5963	0.0014	0.0035	7,104,860	G	2	367	-1.5
604	10/21/85	74.22	674.42	2.1871	(123.0)	4.4380	0.0054	23.4947	0.03829	0.10856	0.5962	0.0014	0.0035	7,099,660	G	2	367	-1.6
605	10/21/85	74.16	673.78	2.1852	(122.8)	4.4324	0.0054	23.4728	0.03827	0.10844	0.5963	0.0014	0.0035	7,094,293	G	2	367	-1.7

Table 28L. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-7A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 0.6251 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.10314 (1984), 0.10214 (1985)

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
541	09/14/84	63.93	636.66	2.0983	(5.9)	0.2145	0.0015	0.08142	0.00018	0.00023	0.5915	0.0027	0.0027	25,318	G 1	345	-8.5
542	09/14/84	64.29	637.45	2.0991	(6.0)	0.2151	0.0015	0.08153	0.00018	0.00023	0.5914	0.0027	0.0027	25,337	G 1	346	-8.5
543	09/14/84	64.63	638.13	2.0997	(6.0)	0.2152	0.0015	0.08163	0.00018	0.00023	0.5918	0.0027	0.0027	25,354	G 1	346	-8.6
544	09/14/84	64.98	638.84	2.1003	(6.0)	0.2157	0.0015	0.08173	0.00018	0.00023	0.5918	0.0027	0.0027	25,370	G 1	347	-8.6
545	09/14/84	68.41	641.67	2.0911	(18.0)	0.6478	0.0016	0.14130	0.00029	0.00038	0.5916	0.0017	0.0026	43,649	G 1	348	-7.9
546	09/14/84	69.21	642.38	2.0893	(18.0)	0.6494	0.0016	0.14139	0.00029	0.00038	0.5915	0.0017	0.0026	43,628	G 1	348	-7.6
547	09/14/84	70.00	643.12	2.0877	(18.0)	0.6503	0.0017	0.14149	0.00029	0.00038	0.5917	0.0018	0.0026	43,610	G 1	349	-7.2
548	09/14/84	70.64	643.77	2.0863	(18.1)	0.6517	0.0018	0.14158	0.00029	0.00038	0.5917	0.0018	0.0026	43,598	G 1	349	-6.9
549	09/14/84	74.32	645.38	2.0727	(45.3)	1.6338	0.0095	0.22373	0.00034	0.00062	0.5922	0.0022	0.0027	68,556	G 2	350	-4.9
550	09/14/84	75.07	646.02	2.0709	(45.3)	1.6356	0.0096	0.22379	0.00034	0.00063	0.5923	0.0022	0.0027	68,502	G 2	350	-4.3
551	09/14/84	75.88	646.64	2.0688	(45.3)	1.6365	0.0095	0.22382	0.00034	0.00063	0.5925	0.0022	0.0027	68,437	G 2	351	-3.7
552	09/14/84	76.49	647.22	2.0678	(45.4)	1.6389	0.0095	0.22388	0.00034	0.00063	0.5924	0.0022	0.0027	68,395	G 2	351	-3.2
553	09/14/84	79.17	648.45	2.0581	(93.6)	3.3793	0.0096	0.32100	0.00075	0.00095	0.5925	0.0019	0.0028	97,713	G 1	352	-0.0
554	09/14/84	79.36	648.96	2.0589	(93.7)	3.3811	0.0095	0.32110	0.00075	0.00095	0.5924	0.0019	0.0028	97,715	G 1	352	0.3
555	09/14/84	79.42	649.46	2.0603	(93.7)	3.3825	0.0095	0.32125	0.00075	0.00095	0.5923	0.0019	0.0028	97,744	G 1	352	0.6
556	09/14/84	79.40	649.91	2.0618	(93.7)	3.3831	0.0095	0.32139	0.00075	0.00096	0.5923	0.0019	0.0028	97,784	G 1	353	0.8
557	09/14/84	79.60	650.37	2.0625	(147.7)	5.3289	0.0095	0.40342	0.00077	0.00120	0.5919	0.0016	0.0028	122,701	G 2	353	1.5
558	09/14/84	79.67	651.05	2.0645	(147.8)	5.3333	0.0095	0.40377	0.00077	0.00120	0.5919	0.0016	0.0028	122,785	G 2	353	1.7
559	09/14/84	79.65	651.61	2.0665	(147.9)	5.3365	0.0095	0.40409	0.00077	0.00121	0.5919	0.0016	0.0028	122,874	G 2	354	1.8
560	09/14/84	79.58	652.21	2.0689	(148.0)	5.3400	0.0095	0.40444	0.00077	0.00121	0.5919	0.0016	0.0028	122,983	G 2	354	1.8

Table 28M. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-7B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 0.6254 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.10319 (1984), 0.10219 (1985)

Run No.	Date	Orifice			Diff. Press.			Mass Flow Rate			Discharge Coefficient			Pipe Rey. Number	Gas/	Num. Noz.	Throat	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
561	09/17/84	71.22	632.72	2.0399	(6.0)	0.2179	0.0055	0.08115	0.00017	0.00022	0.5926	0.0076	0.0027	25,021	G	1	343	-11.4
562	09/17/84	71.75	633.21	2.0389	(6.0)	0.2158	0.0053	0.08115	0.00017	0.00022	0.5957	0.0074	0.0027	25,003	G	1	343	-10.9
563	09/17/84	72.26	632.94	2.0353	(5.9)	0.2136	0.0057	0.08106	0.00017	0.00022	0.5986	0.0081	0.0027	24,960	G	1	343	-10.5
564	09/17/84	72.89	633.51	2.0346	(6.1)	0.2185	0.0054	0.08108	0.00017	0.00023	0.5920	0.0075	0.0027	24,944	G	1	344	-9.9
565	09/17/84	77.21	633.78	2.0136	(17.7)	0.6395	0.0054	0.13901	0.00029	0.00038	0.5963	0.0030	0.0027	42,530	G	1	344	-6.2
566	09/17/84	78.15	633.93	2.0095	(17.7)	0.6404	0.0058	0.13887	0.00029	0.00038	0.5958	0.0032	0.0027	42,435	G	1	344	-5.3
567	09/17/84	79.02	634.22	2.0061	(17.8)	0.6407	0.0054	0.13877	0.00029	0.00038	0.5958	0.0030	0.0027	42,356	G	1	344	-4.4
568	09/17/84	79.79	634.53	2.0036	(17.8)	0.6409	0.0054	0.13870	0.00029	0.00038	0.5957	0.0030	0.0027	42,290	G	1	344	-3.7
569	09/17/84	84.99	634.96	1.9796	(44.3)	1.5997	0.0113	0.21756	0.00034	0.00063	0.5948	0.0025	0.0028	65,899	G	2	345	2.2
570	09/17/84	85.46	635.58	1.9796	(44.4)	1.6041	0.0099	0.21752	0.00034	0.00063	0.5939	0.0023	0.0028	65,839	G	2	345	3.1
571	09/17/84	85.92	636.14	1.9793	(44.3)	1.5987	0.0102	0.21759	0.00036	0.00064	0.5951	0.0024	0.0028	65,816	G	2	345	3.5
572	09/17/84	86.39	636.86	1.9794	(44.4)	1.6016	0.0099	0.21754	0.00033	0.00064	0.5944	0.0023	0.0028	65,756	G	2	346	4.6
573	09/18/84	82.00	659.85	2.0754	(95.1)	3.4321	0.0110	0.32704	0.00055	0.00096	0.5959	0.0017	0.0028	99,074	G	1	358	-1.8
574	09/18/84	82.98	659.79	2.0702	(94.8)	3.4221	0.0115	0.32648	0.00055	0.00096	0.5965	0.0017	0.0028	98,785	G	1	358	-0.7
575	09/18/84	84.02	659.58	2.0642	(94.7)	3.4161	0.0100	0.32576	0.00055	0.00097	0.5965	0.0016	0.0028	98,444	G	1	358	0.7
576	09/18/84	84.62	658.75	2.0587	(94.5)	3.4097	0.0124	0.32497	0.00055	0.00097	0.5964	0.0017	0.0028	98,142	G	1	357	1.6
577	09/18/84	87.11	654.70	2.0334	(147.5)	5.3232	0.0085	0.40288	0.00125	0.00123	0.5950	0.0021	0.0029	121,354	G	2	355	7.1
578	09/18/84	87.54	654.53	2.0307	(147.3)	5.3163	0.0092	0.40271	0.00056	0.00123	0.5956	0.0013	0.0029	121,241	G	2	355	6.5
373	09/16/85	95.58	669.58	2.0784	(6.7)	0.2432	0.0023	0.08361	0.00014	0.00027	0.5723	0.0030	0.0028	24,582	G	1	364	16.3
374	09/16/85	95.21	668.46	2.0765	(6.7)	0.2435	0.0024	0.08351	0.00014	0.00027	0.5715	0.0031	0.0028	24,566	G	1	363	15.9
375	09/16/85	94.95	668.48	2.0778	(6.7)	0.2412	0.0022	0.08354	0.00014	0.00027	0.5742	0.0030	0.0028	24,583	G	1	363	15.6
376	09/16/85	94.66	667.94	2.0775	(6.7)	0.2422	0.0023	0.08350	0.00014	0.00027	0.5728	0.0030	0.0028	24,583	G	1	363	15.3
377	09/16/85	94.36	664.93	2.0641	(18.5)	0.6673	0.0031	0.14294	0.00022	0.00044	0.5926	0.0019	0.0028	42,126	G	1	361	15.1
378	09/16/85	94.28	663.61	2.0601	(18.5)	0.6666	0.0034	0.14265	0.00022	0.00044	0.5923	0.0020	0.0028	42,055	G	1	360	15.1
379	09/16/85	94.15	663.51	2.0604	(18.5)	0.6671	0.0033	0.14265	0.00022	0.00044	0.5921	0.0019	0.0028	42,061	G	1	360	14.9
380	09/16/85	93.98	663.16	2.0601	(18.5)	0.6662	0.0030	0.14261	0.00022	0.00044	0.5923	0.0019	0.0028	42,059	G	1	360	14.8
381	09/17/85	95.01	692.42	2.1513	(201.5)	7.2707	0.0065	0.48666	0.00101	0.00154	0.5976	0.0018	0.0029	142,704	G	2	376	15.9
382	09/17/85	95.18	692.65	2.1513	(201.5)	7.2727	0.0064	0.48673	0.00101	0.00155	0.5976	0.0018	0.0029	142,692	G	2	376	16.1
383	09/17/85	95.29	692.92	2.1516	(201.6)	7.2752	0.0065	0.48687	0.00101	0.00155	0.5976	0.0018	0.0029	142,707	G	2	376	16.2
384	09/17/85	95.23	693.27	2.1530	(201.7)	7.2790	0.0064	0.48712	0.00101	0.00155	0.5975	0.0018	0.0029	142,784	G	2	376	16.2

Table 28M. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-7B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 0.6254 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.10319 (1984), 0.10219 (1985)

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
385	09/17/85	94.99	676.96	2.0984	(94.5)	3.4120	0.0072	0.32971	0.00093	0.00106	0.5991	0.0022	0.0029	96,901	G 1	367	16.4
386	09/17/85	94.64	675.30	2.0937	(94.3)	3.4017	0.0078	0.32893	0.00093	0.00106	0.5992	0.0022	0.0029	96,745	G 1	366	16.1
387	09/17/85	94.50	674.20	2.0907	(94.1)	3.3960	0.0079	0.32841	0.00093	0.00106	0.5992	0.0022	0.0029	96,624	G 1	366	15.9
388	09/17/85	94.39	673.18	2.0879	(94.0)	3.3927	0.0072	0.32795	0.00093	0.00105	0.5991	0.0022	0.0029	96,516	G 1	365	15.8

Table 28N. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-8A Mounted in Meter Tube FE-7ABC

Orifice Diameter = 1.2503 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.20630 (1984), 0.20430 (1985)

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
521	09/12/84	92.16	638.45	1.9574	(5.7)	0.2050	0.0044	0.30908	0.00070	0.00099	0.5937	0.0066	0.0028	92,715	G 1	346	14.5
522	09/12/84	92.76	637.56	1.9517	(5.7)	0.2051	0.0039	0.30848	0.00070	0.00099	0.5932	0.0058	0.0028	92,479	G 1	346	14.8
523	09/12/84	93.24	636.51	1.9460	(5.7)	0.2041	0.0042	0.30784	0.00070	0.00099	0.5942	0.0064	0.0028	92,244	G 1	345	15.2
524	09/12/84	93.62	635.75	1.9420	(5.7)	0.2043	0.0041	0.30737	0.00070	0.00099	0.5936	0.0062	0.0028	92,069	G 1	345	15.4
525	09/12/84	92.64	631.24	1.9322	(17.1)	0.6174	0.0042	0.53662	0.00104	0.00170	0.5977	0.0025	0.0028	161,048	G 1	343	15.2
526	09/12/84	92.38	630.36	1.9305	(17.1)	0.6185	0.0042	0.53592	0.00104	0.00169	0.5966	0.0026	0.0028	160,910	G 1	342	15.1
527	09/12/84	92.07	629.64	1.9296	(17.1)	0.6170	0.0038	0.53537	0.00104	0.00169	0.5969	0.0024	0.0028	160,822	G 1	342	14.9
528	09/12/84	91.71	629.09	1.9294	(17.0)	0.6151	0.0037	0.53507	0.00104	0.00169	0.5975	0.0024	0.0028	160,816	G 1	341	14.7
529	09/13/84	81.05	615.44	1.9388	(41.3)	1.4921	0.0098	0.83314	0.00132	0.00251	0.5958	0.0024	0.0027	254,230	G 2	334	4.6
530	09/13/84	81.14	615.36	1.9380	(41.4)	1.4925	0.0098	0.83272	0.00132	0.00251	0.5956	0.0024	0.0027	254,080	G 2	334	4.8
531	09/13/84	80.90	615.28	1.9388	(41.3)	1.4917	0.0098	0.83274	0.00132	0.00251	0.5956	0.0024	0.0027	254,168	G 2	334	4.7
532	09/13/84	80.86	615.22	1.9388	(41.3)	1.4918	0.0098	0.83271	0.00132	0.00251	0.5956	0.0024	0.0027	254,173	G 2	334	4.6
533	09/13/84	80.99	612.99	1.9308	(84.8)	3.0618	0.0099	1.19019	0.00264	0.00353	0.5951	0.0019	0.0026	363,344	G 1	332	4.7
534	09/13/84	81.13	612.79	1.9296	(84.8)	3.0612	0.0099	1.18981	0.00266	0.00353	0.5952	0.0019	0.0026	363,173	G 1	332	4.7
535	09/13/84	81.29	612.58	1.9281	(84.8)	3.0602	0.0099	1.18921	0.00269	0.00353	0.5952	0.0019	0.0026	362,925	G 1	332	4.8
536	09/13/84	81.28	612.39	1.9275	(84.8)	3.0595	0.0100	1.18866	0.00264	0.00353	0.5951	0.0019	0.0026	362,777	G 1	332	4.9
537	09/13/84	81.69	609.90	1.9173	(132.6)	4.7840	0.0101	1.48242	0.00274	0.00443	0.5947	0.0016	0.0027	452,353	G 2	331	5.2
538	09/13/84	81.72	609.73	1.9166	(132.5)	4.7837	0.0100	1.48187	0.00274	0.00443	0.5946	0.0016	0.0027	452,180	G 2	331	5.3
539	09/13/84	81.70	609.53	1.9160	(132.5)	4.7824	0.0099	1.48132	0.00274	0.00443	0.5946	0.0016	0.0027	452,039	G 2	331	5.3
540	09/13/84	81.93	609.36	1.9144	(132.5)	4.7819	0.0099	1.48065	0.00274	0.00443	0.5946	0.0016	0.0027	451,712	G 2	331	5.4

Table 280. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-8B Mounted in Meter Tube FE-7ABC

Orifice Diameter = 0.6234 Inches -- Tube Diameter = 6.0606 Inches (1984), 6.1200 Inches (1985); Beta Ratio = 0.10286 (1984), 0.10186 (1985)

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge Coefficient ---- Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
720	11/01/85	79.17	724.46	2.3498	(6.9)	0.2479	0.0011	0.09275	0.00021	0.00027	0.5954	0.0022	0.0027	27,595	G 1	393	-0.9
721	11/01/85	78.13	725.51	2.3599	(6.9)	0.2476	0.0011	0.09300	0.00021	0.00027	0.5961	0.0022	0.0027	27,698	G 1	394	-1.7
722	11/01/85	77.36	726.38	2.3677	(6.9)	0.2474	0.0011	0.09320	0.00021	0.00027	0.5966	0.0022	0.0027	27,779	G 1	394	-2.3
723	11/01/85	76.70	727.23	2.3751	(6.9)	0.2472	0.0012	0.09339	0.00021	0.00027	0.5971	0.0022	0.0027	27,854	G 1	394	-2.8
724	11/01/85	84.96	723.37	2.3116	(211.5)	7.6315	0.0038	0.51651	0.00103	0.00155	0.6011	0.0016	0.0028	152,637	G 2	392	6.0
725	11/01/85	85.16	723.74	2.3096	(211.5)	7.6344	0.0037	0.51642	0.00103	0.00156	0.6011	0.0016	0.0028	152,571	G 2	392	6.2
726	11/01/85	85.33	723.95	2.3094	(211.4)	7.6314	0.0047	0.51641	0.00103	0.00156	0.6013	0.0016	0.0028	152,535	G 2	393	6.4
727	11/01/85	85.45	723.98	2.3088	(211.4)	7.6296	0.0044	0.51630	0.00103	0.00156	0.6013	0.0016	0.0028	152,479	G 2	393	6.6
728	11/01/85	85.74	725.68	2.3139	(161.6)	5.8318	0.0049	0.45142	0.00100	0.00138	0.6010	0.0017	0.0028	133,230	G 2	394	5.8
729	11/01/85	85.78	725.68	2.3136	(161.4)	5.8260	0.0039	0.45132	0.00100	0.00138	0.6012	0.0017	0.0028	133,195	G 2	394	6.2
730	11/01/85	85.85	726.03	2.3144	(161.4)	5.8235	0.0077	0.45146	0.00100	0.00138	0.6014	0.0017	0.0028	133,217	G 2	394	6.4
731	11/01/85	85.84	726.24	2.3152	(161.5)	5.8275	0.0043	0.45156	0.00100	0.00138	0.6012	0.0017	0.0028	133,245	G 2	394	6.5
732	11/01/85	84.96	730.44	2.3348	(102.5)	3.6986	0.0037	0.36216	0.00098	0.00111	0.6031	0.0019	0.0028	106,907	G 1	396	6.1
733	11/01/85	84.83	730.94	2.3374	(102.6)	3.7022	0.0041	0.36248	0.00098	0.00111	0.6030	0.0019	0.0028	107,008	G 1	396	6.0
734	11/01/85	84.67	731.45	2.3401	(102.6)	3.7038	0.0040	0.36283	0.00098	0.00111	0.6031	0.0019	0.0028	107,124	G 1	397	5.8
735	11/01/85	84.49	731.92	2.3428	(102.7)	3.7072	0.0041	0.36314	0.00098	0.00111	0.6030	0.0019	0.0028	107,231	G 1	397	5.7
736	11/01/85	83.45	735.34	2.3609	(51.2)	1.8468	0.0035	0.25429	0.00040	0.00075	0.5963	0.0015	0.0027	75,141	G 2	399	4.4
737	11/01/85	83.13	736.02	2.3653	(51.1)	1.8449	0.0036	0.25460	0.00040	0.00075	0.5968	0.0015	0.0027	75,252	G 2	399	4.3
738	11/01/85	82.90	736.73	2.3692	(51.2)	1.8474	0.0037	0.25492	0.00041	0.00075	0.5967	0.0015	0.0027	75,358	G 2	400	4.2
739	11/01/85	82.70	737.27	2.3723	(51.2)	1.8481	0.0035	0.25517	0.00041	0.00075	0.5967	0.0015	0.0027	75,444	G 2	400	4.0

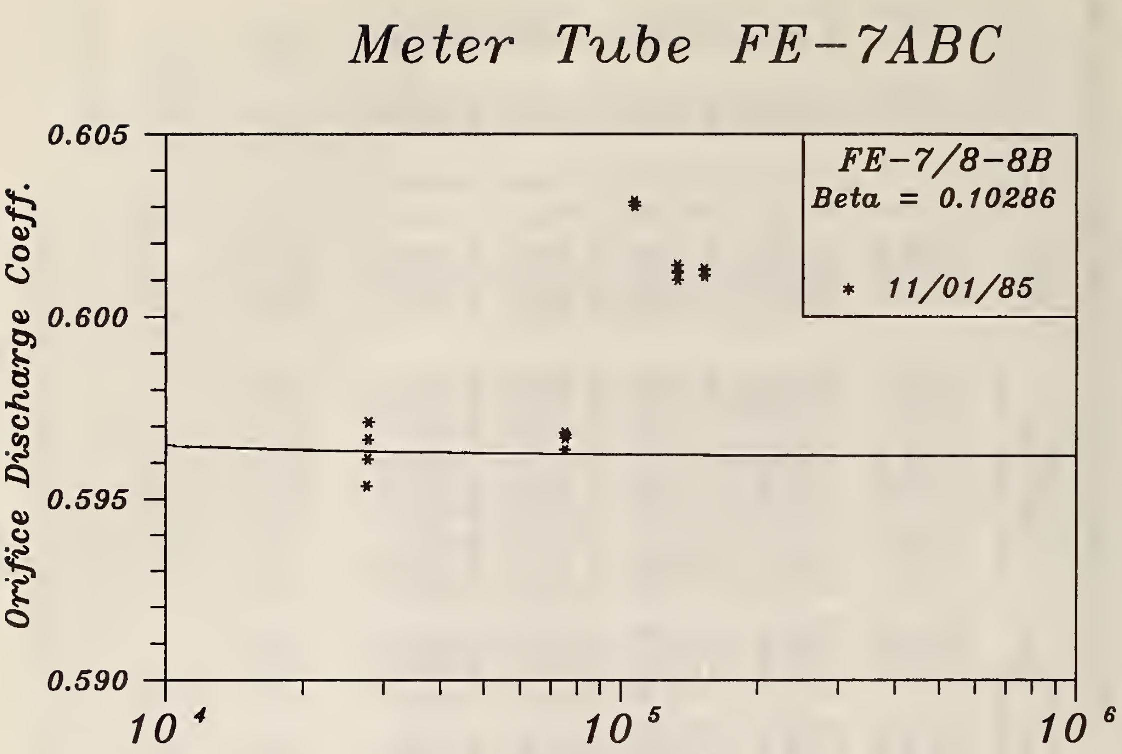


Figure 10A. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

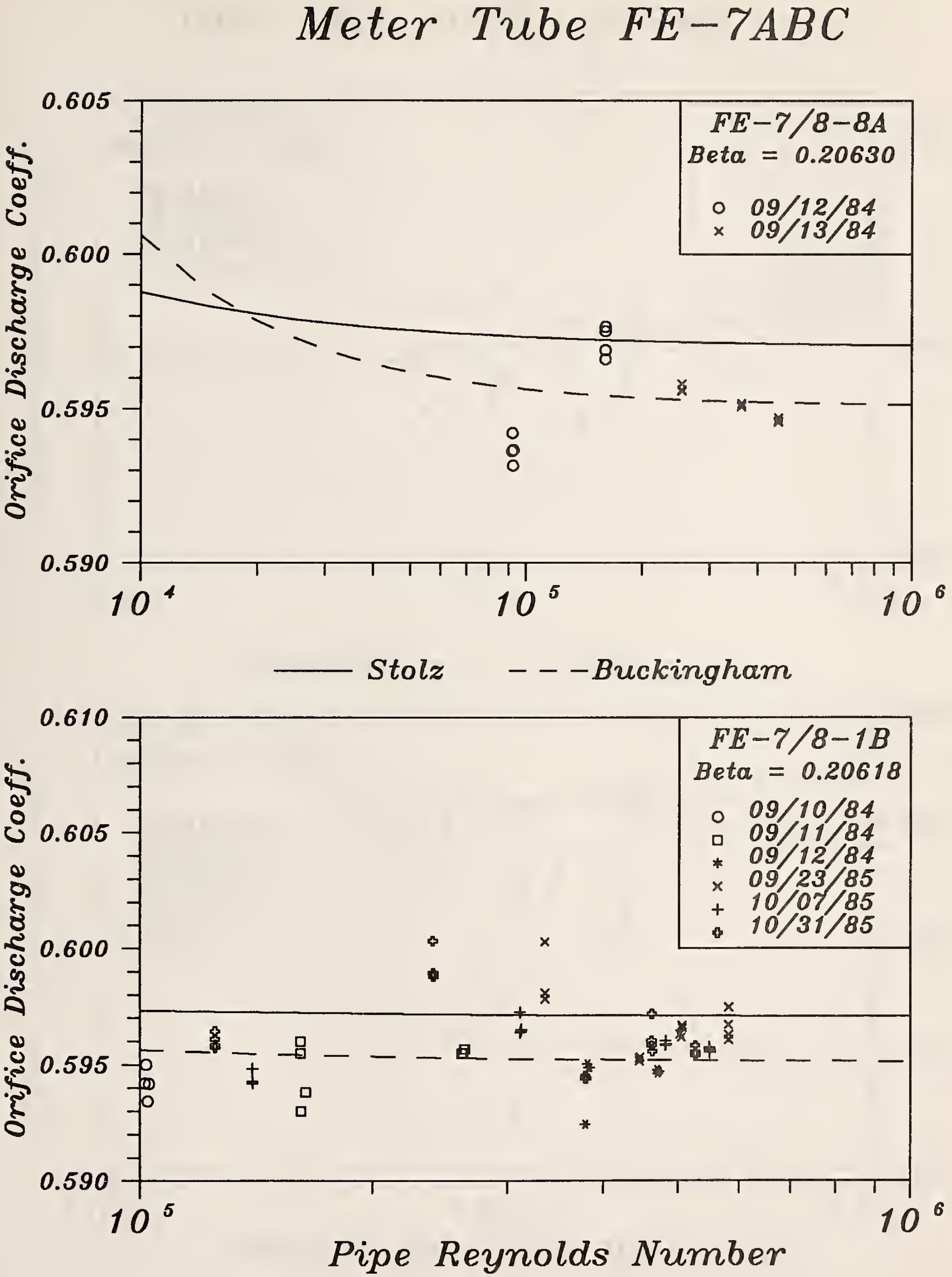


Figure 10B. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

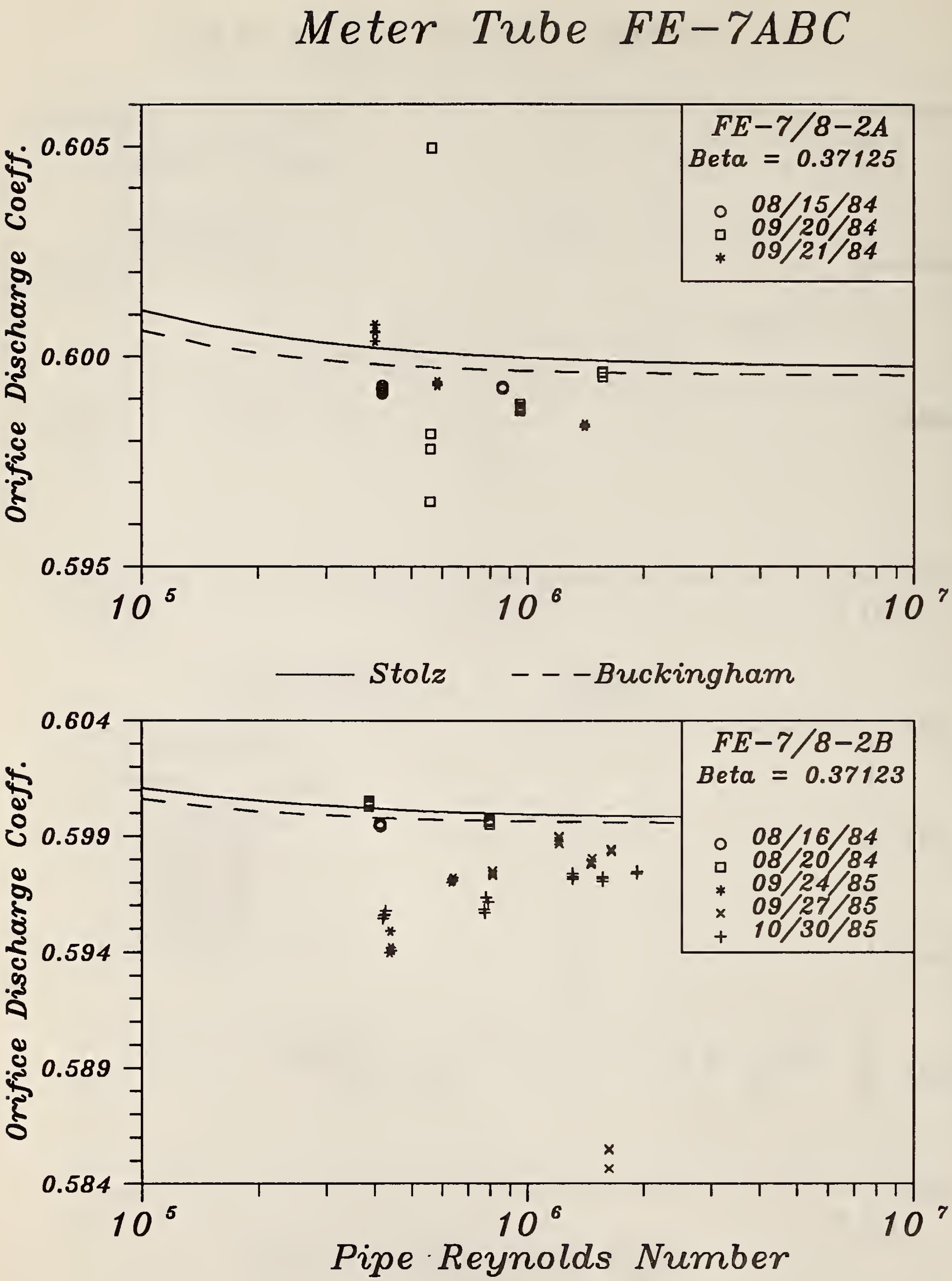


Figure 10C. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

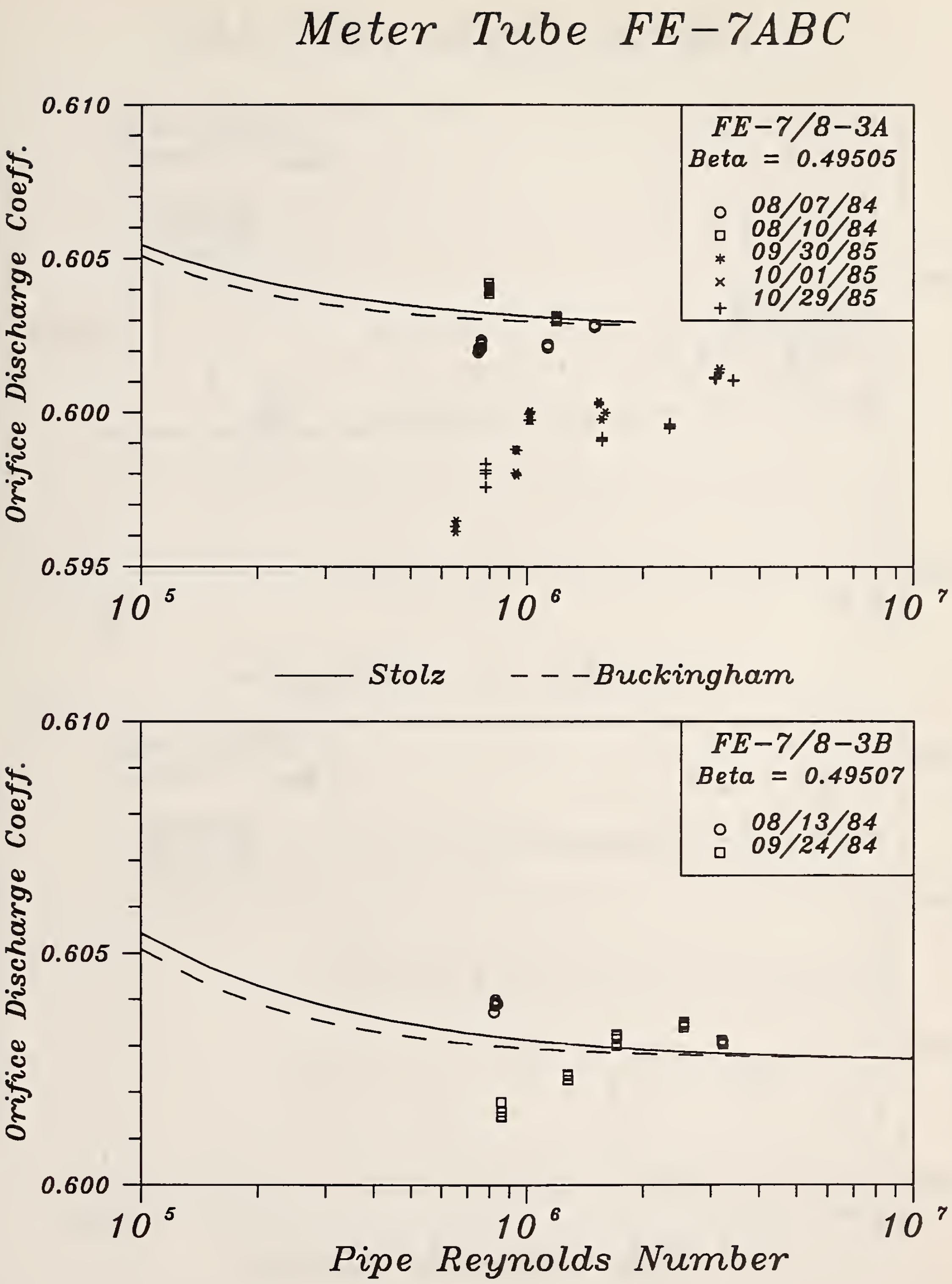


Figure 10D. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

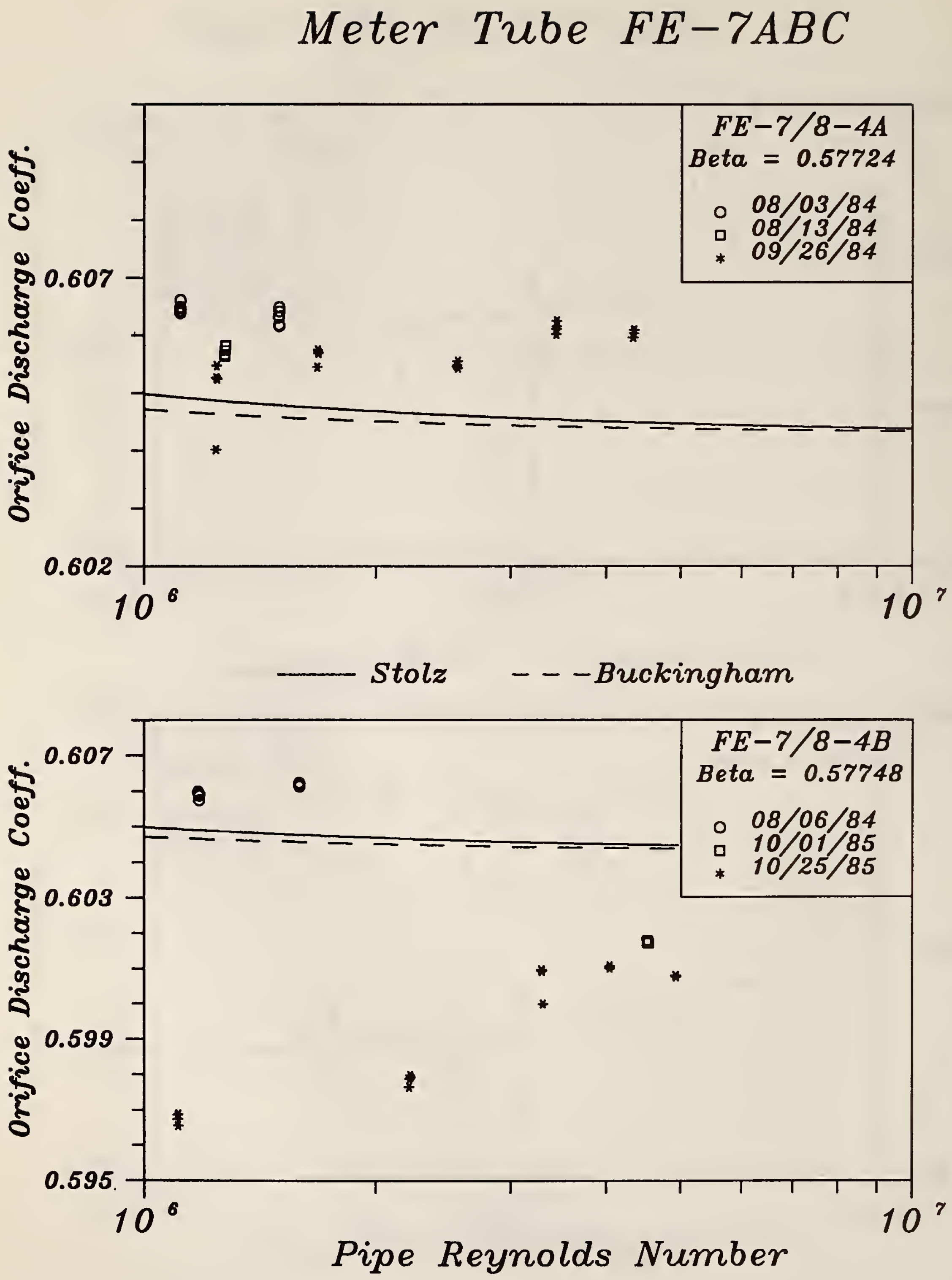


Figure 10E. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

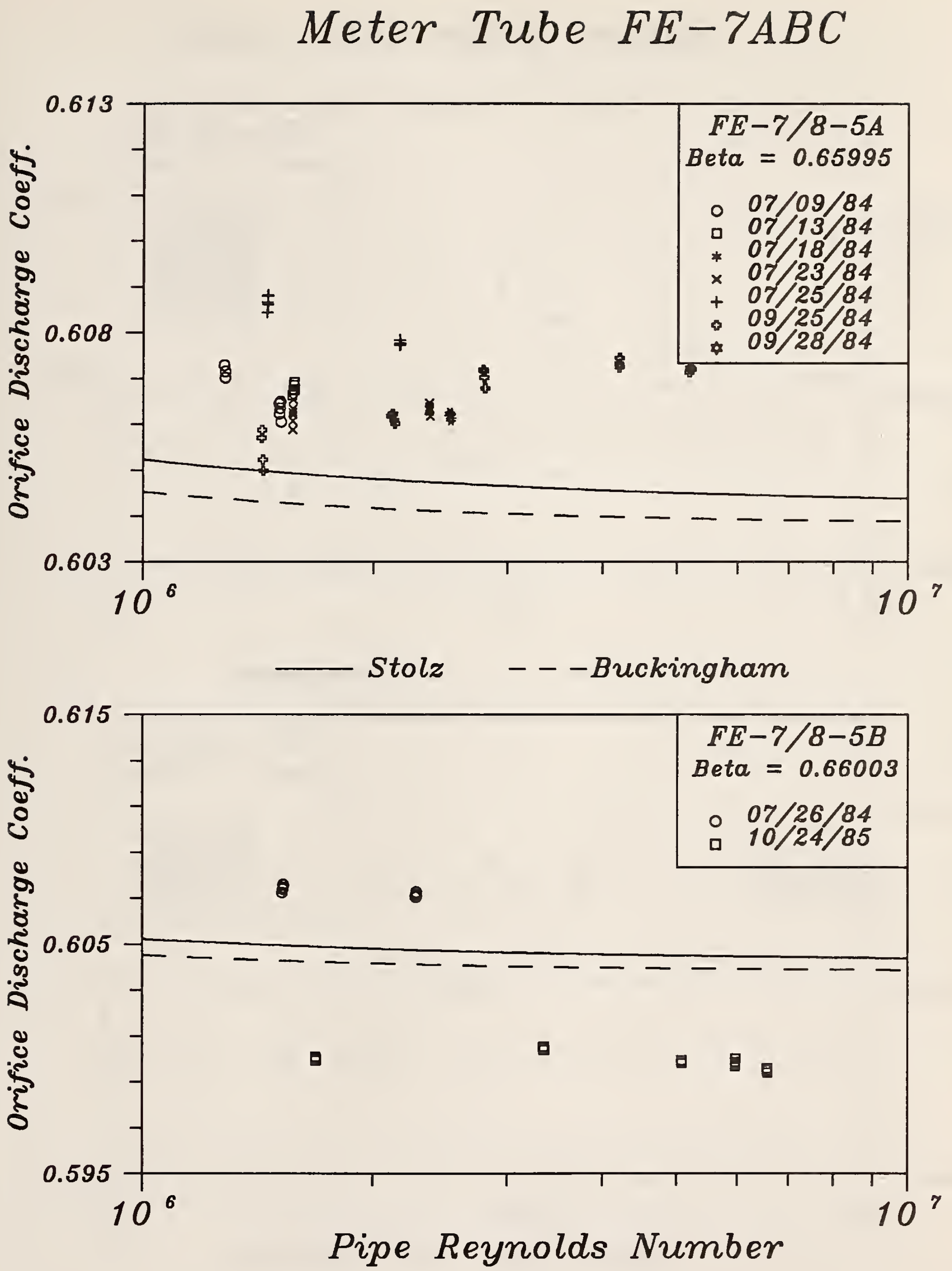


Figure 10F. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

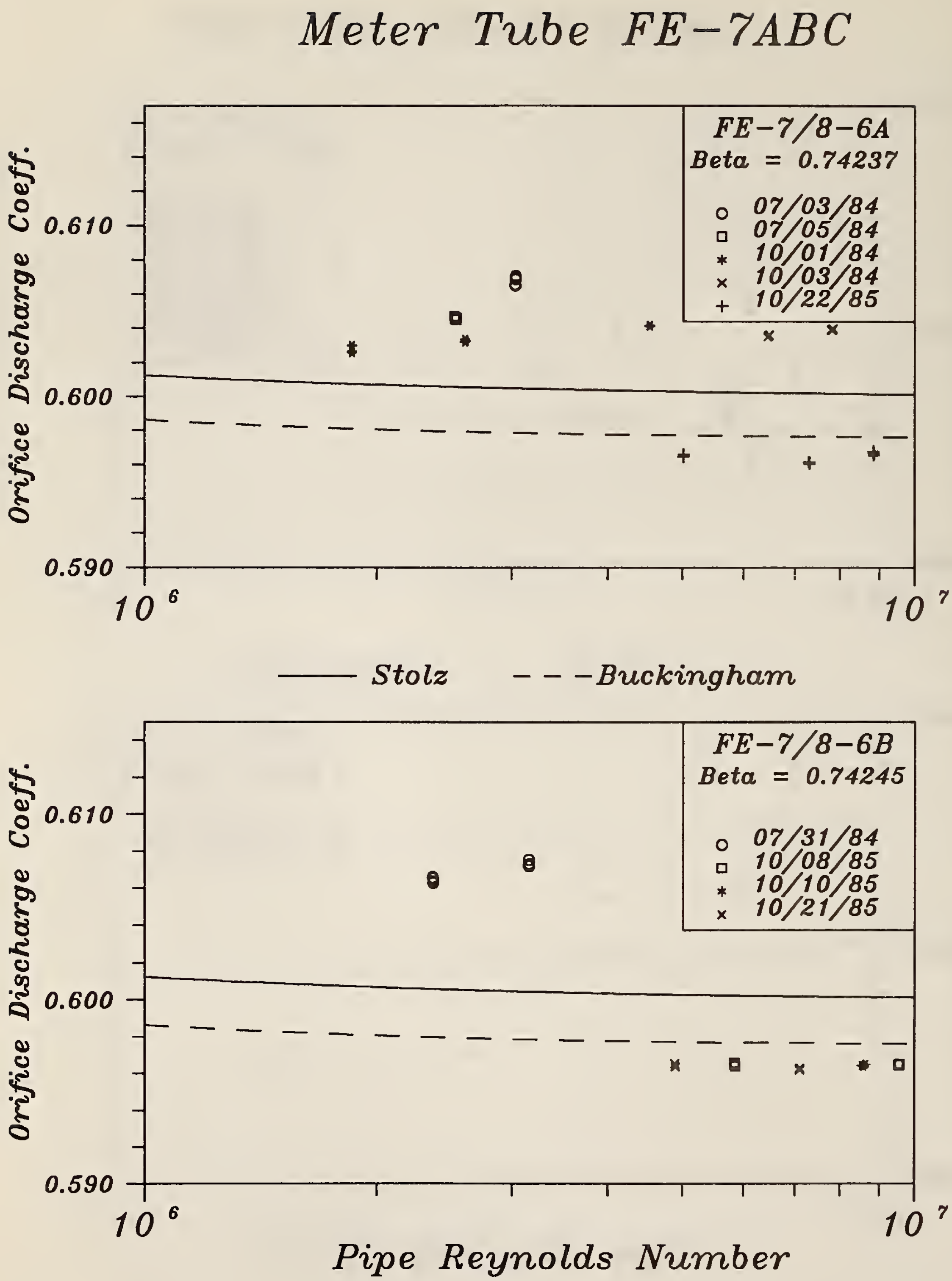


Figure 10G. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

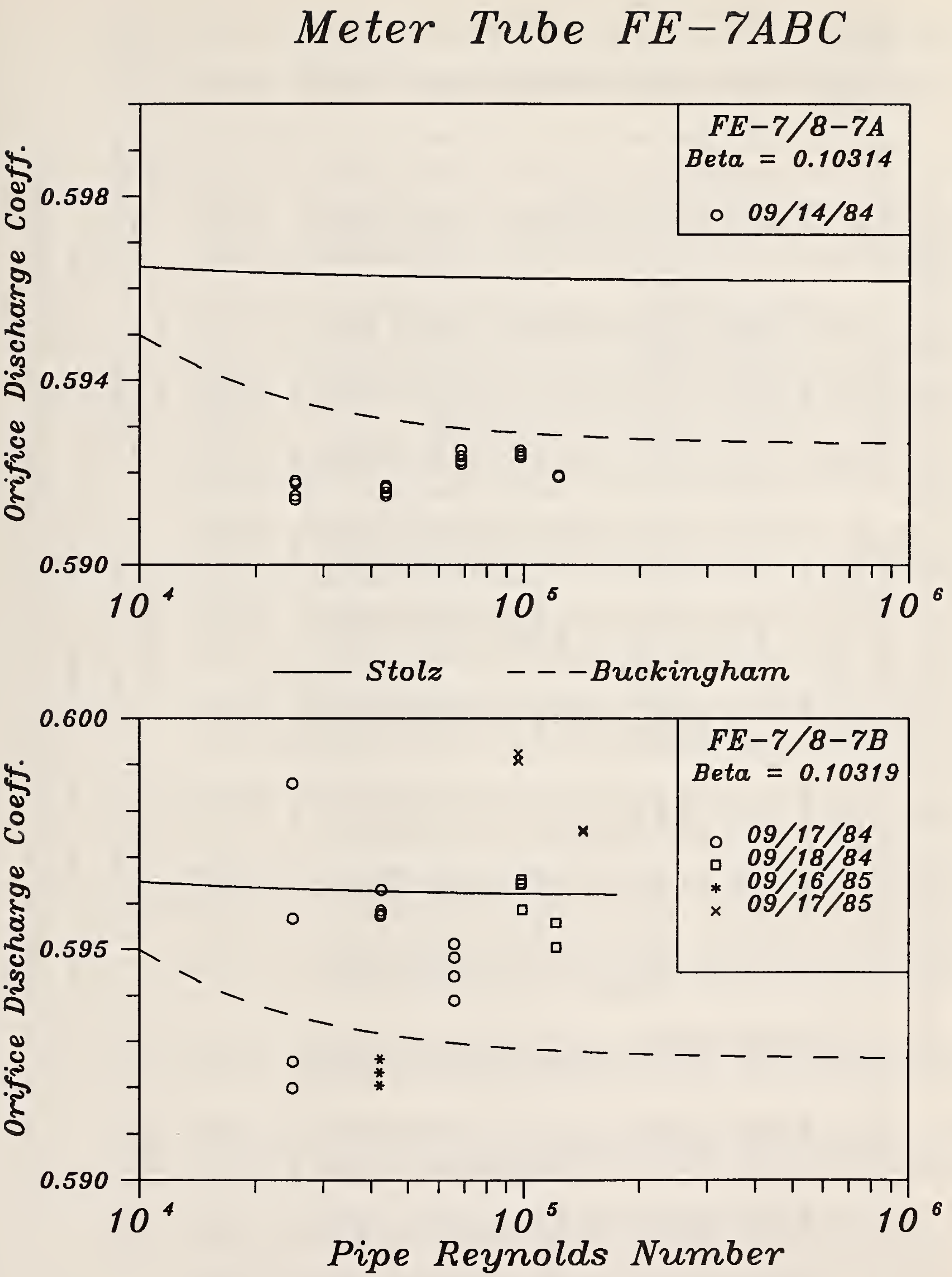


Figure 10H. Discharge coefficient/Reynolds number plots, FE-7ABC, 6-inch meter tube, 15 orifice plates.

Table 29A. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-1B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 1.2496 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.20543

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
864	11/18/85	86.80	673.97	2.1164	(12.6)	0.4561	0.0021	0.47679	0.00069	0.00145	0.5911	0.0018	0.0026	142,849	G 2	366	7.7
865	11/18/85	87.30	673.05	2.1107	(12.7)	0.4575	0.0023	0.47589	0.00068	0.00145	0.5899	0.0019	0.0026	142,512	G 2	365	8.0
866	11/18/85	87.75	672.74	2.1073	(12.6)	0.4550	0.0027	0.47542	0.00068	0.00145	0.5914	0.0022	0.0026	142,299	G 2	365	8.4
867	11/18/85	88.05	672.55	2.1051	(12.6)	0.4558	0.0020	0.47509	0.00068	0.00145	0.5908	0.0018	0.0026	142,152	G 2	365	8.7
868	11/18/85	86.67	670.64	2.1054	(45.7)	1.6506	0.0043	0.90707	0.00102	0.00279	0.5925	0.0014	0.0026	271,952	G 2	364	8.6
869	11/18/85	86.34	670.51	2.1067	(45.4)	1.6370	0.0107	0.90736	0.00102	0.00278	0.5949	0.0023	0.0026	272,156	G 2	364	8.3
870	11/18/85	86.18	670.35	2.1070	(45.6)	1.6474	0.0044	0.90728	0.00102	0.00278	0.5930	0.0014	0.0026	272,190	G 2	364	8.2
871	11/18/85	85.90	670.32	2.1085	(45.5)	1.6423	0.0077	0.90758	0.00102	0.00278	0.5939	0.0018	0.0026	272,374	G 2	364	7.9
873	11/18/85	87.31	666.04	2.0876	(92.5)	3.3374	0.0052	1.29045	0.00193	0.00393	0.5950	0.0014	0.0026	386,828	G 1	361	9.7
874	11/18/85	87.43	665.71	2.0858	(92.4)	3.3343	0.0054	1.28959	0.00193	0.00393	0.5951	0.0014	0.0026	386,528	G 1	361	9.8
875	11/18/85	87.47	665.49	2.0849	(92.3)	3.3327	0.0047	1.28904	0.00193	0.00393	0.5951	0.0014	0.0026	386,358	G 1	360	9.8
876	11/18/85	87.45	665.40	2.0847	(92.3)	3.3310	0.0050	1.28886	0.00193	0.00393	0.5952	0.0014	0.0026	386,318	G 1	360	9.8
877	11/18/85	88.55	663.49	2.0742	(144.3)	5.2069	0.0054	1.60851	0.00203	0.00495	0.5953	0.0013	0.0027	481,521	G 2	360	10.5
878	11/18/85	88.81	663.67	2.0735	(144.2)	5.2027	0.0054	1.60840	0.00203	0.00495	0.5956	0.0013	0.0027	481,322	G 2	360	10.7
879	11/18/85	89.12	663.83	2.0724	(144.0)	5.1957	0.0178	1.60813	0.00203	0.00496	0.5960	0.0016	0.0027	481,046	G 2	360	11.0
880	11/18/85	89.21	664.05	2.0727	(144.1)	5.2003	0.0101	1.60851	0.00203	0.00496	0.5958	0.0013	0.0027	481,091	G 2	360	11.2
881	11/18/85	89.57	665.42	2.0779	(192.0)	6.9309	0.0070	1.85852	0.00208	0.00574	0.5953	0.0012	0.0027	555,374	G 2	361	11.9
882	11/18/85	89.79	665.95	2.0786	(192.1)	6.9329	0.0095	1.85961	0.00208	0.00575	0.5954	0.0012	0.0027	555,505	G 2	361	12.0
883	11/18/85	89.90	666.34	2.0794	(192.3)	6.9385	0.0056	1.86044	0.00208	0.00575	0.5953	0.0012	0.0027	555,649	G 2	361	12.2
884	11/18/85	89.81	666.63	2.0808	(192.1)	6.9318	0.0210	1.86145	0.00208	0.00576	0.5957	0.0015	0.0027	555,989	G 2	361	12.1

Table 29B. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 2.2499 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.36987

Run No.	Date	Orifice Temp. (°F)	Orifice Press. (Psia)	Orifice Density (lb/CF)	Diff. Press. (in.)	Diff. Press. Mean (psi)	Diff. Press. Std. Dev. (psi)	Mass Flow Rate Total (pounds/second)	Mass Flow Rate Rand. (pounds/second)	Mass Flow Rate Syst. (pounds/second)	Discharge Coefficient Mean	Discharge Coefficient Rand.	Discharge Coefficient Syst.	Pipe Rey. Number	Gas/ Num. Noz.	Throat Press. (Psia)	Throat Temp. (°F)°
822	11/12/85	94.12	636.11	1.9861	(12.8)	0.4630	0.0033	1.53915	0.00202	0.00487	0.5978	0.0025	0.0027	459,223	G 2	345	16.0
823	11/12/85	93.68	637.04	1.9915	(12.9)	0.4641	0.0040	1.54240	0.00202	0.00487	0.5976	0.0028	0.0027	460,380	G 2	346	15.6
824	11/12/85	93.50	637.86	1.9951	(12.9)	0.4647	0.0049	1.54491	0.00202	0.00487	0.5977	0.0034	0.0027	461,178	G 2	346	15.4
825	11/12/85	93.27	638.49	1.9985	(12.8)	0.4637	0.0038	1.54698	0.00202	0.00488	0.5986	0.0027	0.0027	461,893	G 2	347	15.2
826	11/12/85	93.63	640.19	2.0022	(43.7)	1.5756	0.0057	2.83843	0.00425	0.00916	0.5951	0.0017	0.0027	846,912	G 2	348	15.2
827	11/12/85	93.95	640.94	2.0031	(43.6)	1.5747	0.0063	2.83934	0.00424	0.00919	0.5953	0.0018	0.0027	846,751	G 2	348	15.7
828	11/12/85	94.08	641.50	2.0044	(43.7)	1.5755	0.0058	2.84098	0.00424	0.00921	0.5953	0.0017	0.0027	847,037	G 2	349	15.9
829	11/12/85	94.20	642.21	2.0062	(43.7)	1.5776	0.0057	2.84344	0.00424	0.00923	0.5951	0.0017	0.0027	847,558	G 2	349	16.1
830	11/12/85	93.57	637.75	1.9942	(99.9)	3.6046	0.0060	4.25968	0.00468	0.01369	0.5912	0.0012	0.0027	1,271,513	G 3	340	16.5
831	11/12/85	93.57	636.96	1.9915	(99.7)	3.5971	0.0089	4.25489	0.00467	0.01368	0.5916	0.0014	0.0027	1,270,215	G 3	340	16.5
832	11/12/85	93.53	636.31	1.9896	(99.5)	3.5925	0.0059	4.25062	0.00467	0.01367	0.5916	0.0012	0.0027	1,269,120	G 3	340	16.5
833	11/12/85	93.65	635.68	1.9869	(99.4)	3.5891	0.0069	4.24728	0.00467	0.01366	0.5919	0.0013	0.0027	1,268,057	G 3	340	16.6
834	11/12/85	93.11	630.50	1.9717	(142.7)	5.1515	0.0061	5.11054	0.00913	0.02459	0.5964	0.0015	0.0036	1,527,925	G 2	343	15.7
835	11/12/85	93.26	629.82	1.9685	(142.7)	5.1492	0.0084	5.10346	0.00913	0.02457	0.5962	0.0015	0.0036	1,525,690	G 2	343	15.8
836	11/12/85	93.40	629.17	1.9656	(142.4)	5.1390	0.0060	5.09732	0.00913	0.02455	0.5965	0.0015	0.0037	1,523,732	G 2	342	16.0
837	11/12/85	93.44	628.57	1.9635	(142.3)	5.1340	0.0061	5.09147	0.00912	0.02453	0.5964	0.0015	0.0037	1,522,037	G 2	342	16.1
838	11/12/85	96.46	622.68	1.9299	(206.6)	7.4556	0.0064	6.09380	0.00928	0.02784	0.5970	0.0014	0.0035	1,816,288	G 2	339	19.1
839	11/12/85	97.41	621.22	1.9208	(206.0)	7.4346	0.0068	6.07215	0.00926	0.02783	0.5971	0.0014	0.0035	1,808,065	G 2	338	20.0
840	11/12/85	97.33	620.26	1.9179	(205.7)	7.4240	0.0061	6.06150	0.00925	0.02779	0.5969	0.0014	0.0035	1,805,324	G 2	337	20.0
841	11/12/85	96.23	619.13	1.9188	(205.1)	7.4039	0.0065	6.05536	0.00927	0.02769	0.5970	0.0014	0.0035	1,806,250	G 2	337	19.3
842	11/12/85	95.72	619.48	1.9226	(86.5)	3.1202	0.0058	3.92111	0.00462	0.01278	0.5958	0.0013	0.0027	1,170,323	G 3	337	18.5
843	11/12/85	94.59	618.22	1.9235	(86.2)	3.1122	0.0058	3.91830	0.00462	0.01270	0.5960	0.0013	0.0027	1,171,338	G 3	336	17.5
844	11/12/85	94.70	617.07	1.9192	(86.1)	3.1064	0.0059	3.91127	0.00461	0.01267	0.5962	0.0013	0.0027	1,169,270	G 3	335	17.4
845	11/12/85	95.47	616.00	1.9121	(86.0)	3.1041	0.0058	3.90192	0.00461	0.01267	0.5960	0.0013	0.0027	1,165,533	G 3	335	17.9
848	11/15/85	92.58	541.31	1.6924	(10.8)	0.3910	0.0024	1.31000	0.00165	0.00413	0.5999	0.0023	0.0028	396,884	G 2	294	14.3
849	11/15/85	92.59	540.87	1.6908	(10.8)	0.3900	0.0025	1.30902	0.00165	0.00412	0.6005	0.0024	0.0028	396,604	G 2	294	14.2
850	11/15/85	92.74	540.38	1.6886	(10.8)	0.3902	0.0024	1.30762	0.00164	0.00412	0.6001	0.0023	0.0028	396,129	G 2	294	14.3
851	11/15/85	92.56	540.25	1.6889	(10.8)	0.3910	0.0026	1.30752	0.00165	0.00412	0.5994	0.0025	0.0028	396,202	G 2	294	14.2
852	11/15/85	92.32	548.75	1.6798	(11.0)	0.3953	0.0019	1.31663	0.00164	0.00412	0.6019	0.0020	0.0028	398,364	G 2	298	12.8
853	11/15/85	92.15	548.23	1.6788	(10.9)	0.3938	0.0020	1.31553	0.00164	0.00588	0.6027	0.0021	0.0036	398,150	G 2	297	12.7
854	11/15/85	92.15	548.00	1.6781	(10.9)	0.3950	0.0019	1.31503	0.00164	0.00411	0.6017	0.0020	0.0028	398,009	G 2	297	12.7
855	11/15/85	92.00	547.61	1.6774	(10.9)	0.3939	0.0019	1.31424	0.00164	0.00410	0.6022	0.0020	0.0028	397,867	G 2	297	12.7

Table 29B. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-2B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 2.2499 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.36987

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand.	Syst.	Coefficient Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
								(pounds/second)									
856	11/15/85	94.74	558.42	1.7015	(44.7)	1.6139	0.0058	2.65366	0.00354	0.00853	0.5962	0.0018	0.0028	799,460	G 2	303	14.8
857	11/15/85	95.82	560.88	1.7050	(44.8)	1.6178	0.0058	2.65997	0.00349	0.00862	0.5963	0.0018	0.0028	800,040	G 2	305	16.3
858	11/15/85	95.59	562.32	1.7106	(44.9)	1.6204	0.0058	2.66582	0.00348	0.00865	0.5962	0.0018	0.0028	801,885	G 2	306	16.6
859	11/15/85	92.62	564.08	1.7278	(44.9)	1.6207	0.0058	2.67977	0.00349	0.00863	0.5963	0.0018	0.0028	809,024	G 2	306	14.9
860	11/15/85	91.23	552.48	1.6952	(98.7)	3.5637	0.0066	3.95378	0.00410	0.01257	0.5985	0.0015	0.0028	1,197,748	G 4	300	13.7
861	11/15/85	91.22	546.19	1.6747	(97.6)	3.5224	0.0065	3.90664	0.00399	0.01243	0.5985	0.0014	0.0028	1,184,495	G 4	297	13.8
862	11/15/85	91.16	542.85	1.6640	(97.0)	3.5026	0.0068	3.88198	0.00388	0.01235	0.5983	0.0015	0.0028	1,177,632	G 4	295	13.8
863	11/15/85	91.43	540.35	1.6549	(96.6)	3.4875	0.0065	3.86241	0.00386	0.01230	0.5982	0.0014	0.0028	1,171,690	G 4	294	14.0

Table 29C. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3A Mounted in Meter Tube PE-8ABC

Orifice Diameter = 3.0003 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.49324

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
802	11/11/85	93.74	566.70	1.7540	(9.1)	0.3295	0.0019	2.22182	0.00347	0.00720	0.5994	0.0023	0.0028	669,786	G 1	308	15.2
803	11/11/85	93.77	564.60	1.7469	(9.1)	0.3284	0.0021	2.21286	0.00347	0.00718	0.5992	0.0024	0.0028	667,252	G 1	307	15.4
804	11/11/85	93.90	563.19	1.7417	(9.1)	0.3268	0.0020	2.20671	0.00346	0.00716	0.5999	0.0024	0.0028	665,418	G 1	306	15.5
805	11/11/85	94.01	561.58	1.7360	(9.0)	0.3261	0.0019	2.19983	0.00346	0.00715	0.5997	0.0023	0.0028	663,336	G 1	306	15.7
806	11/11/85	94.67	553.43	1.7067	(35.7)	1.2885	0.0030	4.33486	0.00964	0.02119	0.5994	0.0019	0.0038	1,307,369	G 1	301	17.5
807	11/11/85	94.66	551.73	1.7011	(35.6)	1.2831	0.0029	4.32119	0.00964	0.02112	0.5997	0.0019	0.0038	1,303,567	G 1	300	17.5
808	11/11/85	94.69	549.97	1.6953	(35.5)	1.2794	0.0027	4.30658	0.00963	0.02106	0.5996	0.0019	0.0038	1,299,428	G 1	299	17.6
809	11/11/85	94.56	547.83	1.6887	(35.3)	1.2735	0.0028	4.28925	0.00962	0.02098	0.5997	0.0019	0.0038	1,294,795	G 1	298	17.6
810	11/11/85	93.16	534.82	1.6514	(104.8)	3.7812	0.0051	7.31407	0.01035	0.03055	0.5996	0.0015	0.0034	2,215,615	G 3	291	16.7
811	11/11/85	93.42	533.09	1.6447	(104.4)	3.7677	0.0053	7.28704	0.01034	0.03048	0.5997	0.0015	0.0034	2,207,202	G 3	290	17.0
812	11/11/85	93.05	530.55	1.6378	(103.9)	3.7509	0.0054	7.25324	0.01033	0.03031	0.5995	0.0015	0.0034	2,198,777	G 3	289	16.7
813	11/11/85	93.04	528.82	1.6325	(103.6)	3.7389	0.0054	7.22965	0.01034	0.03021	0.5995	0.0016	0.0034	2,192,060	G 3	288	16.7
814	11/11/85	91.66	514.75	1.5917	(142.8)	5.1545	0.0056	8.41593	0.01882	0.04066	0.6016	0.0019	0.0038	2,561,162	G 3	281	14.0
815	11/11/85	91.69	512.24	1.5832	(142.2)	5.1305	0.0056	8.37304	0.01874	0.04047	0.6015	0.0019	0.0038	2,548,819	G 3	279	14.4
816	11/11/85	91.65	510.84	1.5788	(141.7)	5.1128	0.0059	8.34925	0.01870	0.04035	0.6017	0.0019	0.0038	2,542,220	G 3	279	14.5
817	11/11/85	91.47	509.52	1.5751	(141.4)	5.1018	0.0057	8.32868	0.01867	0.04024	0.6016	0.0019	0.0038	2,536,973	G 3	278	14.5
818	11/11/85	89.44	496.21	1.5393	(197.3)	7.1222	0.0066	9.73007	0.01867	0.04428	0.6012	0.0018	0.0037	2,977,206	G 2	271	14.0
819	11/11/85	89.65	495.74	1.5370	(197.2)	7.1165	0.0064	9.71914	0.01866	0.04425	0.6012	0.0018	0.0037	2,973,228	G 2	271	14.1
820	11/11/85	89.52	495.36	1.5362	(197.0)	7.1103	0.0065	9.71164	0.01865	0.04421	0.6012	0.0018	0.0037	2,971,611	G 2	270	14.0
821	11/11/85	89.66	494.82	1.5339	(196.9)	7.1059	0.0063	9.69940	0.01863	0.04417	0.6011	0.0018	0.0037	2,967,488	G 2	270	14.1
913	11/21/85	98.05	568.96	1.7218	(9.2)	0.3333	0.0047	2.20852	0.00452	0.00725	0.5979	0.0045	0.0028	661,769	G 1	309	17.8
914	11/21/85	96.25	567.99	1.7259	(9.2)	0.3314	0.0047	2.20632	0.00452	0.00722	0.5983	0.0045	0.0028	662,719	G 1	308	17.2
915	11/21/85	95.22	567.59	1.7286	(9.2)	0.3310	0.0047	2.20674	0.00452	0.00720	0.5984	0.0046	0.0028	663,759	G 1	308	16.5
916	11/21/85	95.26	567.16	1.7271	(9.2)	0.3307	0.0047	2.20524	0.00452	0.00719	0.5984	0.0046	0.0028	663,312	G 1	308	16.4
917	11/21/85	95.78	564.33	1.7155	(36.5)	1.3187	0.0052	4.39038	0.00877	0.02147	0.5985	0.0020	0.0038	1,320,203	G 1	307	17.7
918	11/21/85	95.83	564.08	1.7145	(36.6)	1.3194	0.0054	4.38843	0.00877	0.02146	0.5982	0.0020	0.0038	1,319,566	G 1	306	17.7
919	11/21/85	96.04	563.95	1.7132	(36.5)	1.3168	0.0053	4.38576	0.00876	0.02147	0.5987	0.0020	0.0038	1,318,431	G 1	306	18.0
920	11/21/85	95.96	563.91	1.7138	(36.5)	1.3175	0.0054	4.38609	0.00877	0.02147	0.5985	0.0020	0.0038	1,318,669	G 1	306	18.0
921	11/21/85	91.01	560.67	1.7228	(110.0)	3.9708	0.0050	7.65415	0.01012	0.03161	0.5995	0.0014	0.0033	2,316,972	G 3	305	13.9
922	11/21/85	92.19	560.88	1.7187	(110.0)	3.9709	0.0054	7.64720	0.01011	0.03170	0.5997	0.0014	0.0033	2,311,263	G 3	305	14.9
923	11/21/85	92.73	561.07	1.7172	(110.1)	3.9741	0.0054	7.64497	0.01010	0.03175	0.5995	0.0014	0.0033	2,308,913	G 3	305	15.4
924	11/21/85	92.61	561.29	1.7184	(110.0)	3.9716	0.0053	7.64757	0.01010	0.03176	0.5997	0.0014	0.0033	2,309,956	G 3	305	15.4

Table 29C. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-3A Mounted in Meter Tube PE-8ABC

Orifice Diameter = 3.0003 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.49324

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
925	11/21/85	90.67	560.92	1.7250	(142.7)	5.1519	0.0055	8.75948	0.02141	0.04267	0.6017	0.0019	0.0038	2,652,598	G 1	305	13.8
926	11/21/85	90.85	561.35	1.7257	(142.9)	5.1572	0.0057	8.76407	0.02141	0.04271	0.6016	0.0019	0.0038	2,653,230	G 1	305	14.0
927	11/21/85	90.74	561.77	1.7275	(142.9)	5.1590	0.0051	8.77141	0.02142	0.04273	0.6017	0.0019	0.0038	2,655,675	G 1	306	13.9
928	11/21/85	90.64	562.21	1.7294	(143.0)	5.1615	0.0054	8.77961	0.02144	0.04276	0.6018	0.0019	0.0038	2,658,337	G 1	306	13.8
929	11/21/85	88.14	561.88	1.7383	(190.3)	6.8673	0.0057	10.1620	0.02161	0.04677	0.6020	0.0017	0.0036	3,087,170	G 3	306	11.0
930	11/21/85	88.13	562.16	1.7392	(190.5)	6.8741	0.0053	10.1671	0.02161	0.04678	0.6018	0.0017	0.0036	3,088,615	G 3	306	11.0
931	11/21/85	88.21	562.31	1.7394	(190.5)	6.8746	0.0056	10.1694	0.02161	0.04680	0.6019	0.0017	0.0036	3,088,944	G 3	306	11.0
932	11/21/85	88.09	562.44	1.7403	(190.6)	6.8774	0.0056	10.1726	0.02162	0.04680	0.6018	0.0017	0.0036	3,090,350	G 3	306	11.0

Table 29D. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-4B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 3.4999 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.57537

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/	Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
780	11/07/85	93.96	621.89	1.9242	(11.4)	0.4110	0.0016	3.62962	0.00690	0.01172	0.5985	0.0021	0.0027	1,085,090	G	2	338	16.8
781	11/07/85	93.24	620.82	1.9240	(11.4)	0.4101	0.0018	3.62723	0.00690	0.01166	0.5988	0.0021	0.0027	1,085,523	G	2	337	16.0
782	11/07/85	93.23	619.88	1.9209	(11.4)	0.4100	0.0017	3.62265	0.00690	0.01163	0.5986	0.0021	0.0027	1,084,301	G	2	336	15.8
783	11/07/85	93.61	618.74	1.9154	(11.3)	0.4093	0.0017	3.61482	0.00690	0.01162	0.5987	0.0021	0.0027	1,081,622	G	2	336	16.0
784	11/07/85	92.87	612.92	1.8980	(45.4)	1.6391	0.0034	7.22046	0.01569	0.03113	0.6001	0.0019	0.0034	2,164,469	G	2	333	15.3
786	11/07/85	95.29	612.91	1.8874	(45.3)	1.6361	0.0034	7.19728	0.01551	0.03133	0.6003	0.0019	0.0034	2,151,122	G	2	333	17.9
787	11/07/85	95.28	612.23	1.8852	(45.3)	1.6340	0.0034	7.18742	0.01551	0.03129	0.6003	0.0019	0.0034	2,148,398	G	2	333	17.9
788	11/07/85	95.31	612.04	1.8845	(45.3)	1.6333	0.0034	7.18493	0.01550	0.03128	0.6003	0.0019	0.0034	2,147,627	G	2	333	17.9
789	11/07/85	95.26	611.92	1.8832	(45.2)	1.6326	0.0034	7.18150	0.01550	0.03126	0.6003	0.0019	0.0034	2,146,844	G	2	333	17.9
790	11/07/85	88.52	606.76	1.8958	(99.6)	3.5929	0.0038	10.7278	0.03073	0.04983	0.6022	0.0022	0.0036	3,236,938	G	2	330	11.9
791	11/07/85	89.31	606.28	1.8910	(99.4)	3.5887	0.0036	10.7097	0.03069	0.04987	0.6023	0.0022	0.0036	3,228,491	G	2	330	12.6
792	11/07/85	89.26	610.38	1.9050	(100.1)	3.6125	0.0038	10.7854	0.03101	0.05021	0.6023	0.0022	0.0036	3,249,657	G	2	332	12.6
793	11/07/85	89.31	612.79	1.9128	(100.5)	3.6264	0.0037	10.8299	0.03087	0.05042	0.6024	0.0021	0.0036	3,261,699	G	2	333	12.6
794	11/07/85	84.65	616.96	1.9482	(151.4)	5.4651	0.0039	13.4269	0.03172	0.05802	0.6026	0.0019	0.0034	4,065,623	G	3	336	8.4
795	11/07/85	84.58	617.89	1.9517	(151.7)	5.4753	0.0039	13.4497	0.03175	0.05810	0.6025	0.0019	0.0034	4,072,303	G	3	336	8.3
796	11/07/85	84.52	618.95	1.9555	(151.9)	5.4839	0.0040	13.4751	0.03177	0.05819	0.6026	0.0019	0.0034	4,079,647	G	3	337	8.2
797	11/07/85	84.43	619.76	1.9588	(152.1)	5.4894	0.0039	13.4947	0.03178	0.05826	0.6027	0.0019	0.0034	4,085,613	G	3	337	8.1
798	11/07/85	79.47	620.03	1.9834	(224.3)	8.0940	0.0045	16.4854	0.04334	0.07791	0.6021	0.0020	0.0036	5,022,669	G	1	338	3.7
799	11/07/85	79.37	621.00	1.9872	(224.5)	8.1030	0.0045	16.5143	0.04337	0.07801	0.6022	0.0020	0.0036	5,031,416	G	1	339	3.6
800	11/07/85	79.24	622.37	1.9926	(225.0)	8.1206	0.0043	16.5558	0.04340	0.07817	0.6023	0.0020	0.0036	5,043,817	G	1	339	3.5
801	11/07/85	79.20	623.03	1.9951	(225.3)	8.1319	0.0046	16.5763	0.04342	0.07825	0.6022	0.0020	0.0036	5,049,857	G	1	340	3.4

Table 29E. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-5B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 4.0002 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.65761

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
740	11/05/85	96.92	596.84	1.8291	(10.6)	0.3826	0.0018	4.66274	0.00745	0.02286	0.5978	0.0020	0.0037	1,392,798	G 1	324	18.7
741	11/05/85	97.10	596.60	1.8275	(10.6)	0.3826	0.0018	4.65941	0.00744	0.02286	0.5977	0.0020	0.0037	1,391,520	G 1	324	18.9
742	11/05/85	97.11	597.16	1.8293	(10.6)	0.3828	0.0018	4.66320	0.00744	0.02289	0.5977	0.0020	0.0037	1,392,535	G 1	324	19.1
743	11/05/85	96.86	597.55	1.8316	(10.6)	0.3832	0.0018	4.66662	0.00744	0.02290	0.5974	0.0020	0.0037	1,393,918	G 1	325	19.0
744	11/05/85	90.39	593.65	1.8459	(41.4)	1.4943	0.0051	9.31667	0.02113	0.04530	0.6016	0.0020	0.0037	2,807,434	G 1	323	13.5
745	11/05/85	90.86	592.61	1.8404	(41.3)	1.4918	0.0051	9.29297	0.02108	0.04527	0.6014	0.0020	0.0037	2,799,020	G 1	322	14.1
746	11/05/85	90.91	592.12	1.8386	(41.3)	1.4912	0.0051	9.28408	0.02106	0.04524	0.6013	0.0020	0.0037	2,796,348	G 1	322	14.1
747	11/05/85	91.07	591.89	1.8371	(41.2)	1.4881	0.0050	9.27822	0.02105	0.04524	0.6017	0.0020	0.0037	2,794,126	G 1	322	14.3
748	11/05/85	83.65	588.65	1.8592	(92.5)	3.3396	0.0054	13.9944	0.02247	0.06657	0.6020	0.0015	0.0037	4,257,150	G 2	321	7.7
749	11/05/85	83.71	588.64	1.8588	(92.5)	3.3400	0.0053	13.9929	0.02246	0.06657	0.6020	0.0015	0.0037	4,256,358	G 2	320	7.8
750	11/05/85	83.75	588.70	1.8589	(92.5)	3.3389	0.0054	13.9946	0.02247	0.06658	0.6021	0.0015	0.0037	4,256,624	G 2	321	7.8
751	11/05/85	83.82	589.13	1.8600	(92.6)	3.3414	0.0053	14.0036	0.02248	0.06664	0.6021	0.0015	0.0037	4,258,692	G 2	321	7.9
752	11/05/85	78.02	596.40	1.9095	(153.0)	5.5219	0.0059	18.2260	0.03354	0.08187	0.6014	0.0015	0.0035	5,579,543	G 2	325	2.6
753	11/05/85	77.91	596.78	1.9113	(153.0)	5.5232	0.0058	18.2421	0.03350	0.08190	0.6015	0.0015	0.0035	5,584,932	G 2	325	2.5
754	11/05/85	77.83	597.30	1.9134	(153.2)	5.5276	0.0058	18.2604	0.03350	0.08196	0.6016	0.0015	0.0035	5,590,649	G 2	325	2.4
755	11/05/85	77.78	597.74	1.9149	(153.3)	5.5326	0.0061	18.2736	0.03352	0.08200	0.6015	0.0015	0.0035	5,595,074	G 2	325	2.3
756	11/05/85	75.39	599.17	1.9307	(196.8)	7.1041	0.0063	20.8153	0.03440	0.09691	0.6019	0.0014	0.0036	6,392,187	G 2	327	0.2
757	11/05/85	75.29	600.33	1.9353	(197.2)	7.1181	0.0063	20.8618	0.03442	0.09708	0.6020	0.0014	0.0036	6,406,185	G 2	328	0.0
758	11/05/85	75.15	600.45	1.9363	(197.2)	7.1161	0.0063	20.8697	0.03440	0.09708	0.6021	0.0014	0.0036	6,409,599	G 2	328	-0.1
759	11/05/85	75.08	600.57	1.9371	(197.3)	7.1196	0.0062	20.8762	0.03440	0.09709	0.6020	0.0014	0.0036	6,412,068	G 2	328	-0.2

Table 29F. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-6B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 4.4997 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.73973

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.		-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
760	11/06/85	91.75	698.42	2.1862	(14.7)	0.5310	0.0014	8.27616	0.01644	0.03545	0.6045	0.0018	0.0033	2,453,927	G	2	379	14.0
761	11/06/85	91.84	698.83	2.1872	(14.7)	0.5316	0.0014	8.28054	0.01644	0.03548	0.6043	0.0018	0.0033	2,454,840	G	2	379	14.1
762	11/06/85	91.69	699.27	2.1894	(14.7)	0.5315	0.0014	8.28699	0.01645	0.03549	0.6045	0.0018	0.0033	2,457,028	G	2	380	13.9
763	11/06/85	91.77	699.77	2.1909	(14.7)	0.5320	0.0014	8.29293	0.01645	0.03553	0.6045	0.0018	0.0033	2,458,328	G	2	380	14.0
764	11/06/85	82.66	698.74	2.2376	(41.5)	1.4967	0.0053	13.9353	0.03630	0.06135	0.5992	0.0022	0.0033	4,177,342	G	2	380	5.9
765	11/06/85	82.69	699.52	2.2401	(41.5)	1.4973	0.0053	13.9513	0.03631	0.06143	0.5994	0.0022	0.0033	4,181,432	G	2	380	6.0
766	11/06/85	82.80	700.47	2.2429	(41.6)	1.5006	0.0054	13.9700	0.03633	0.06153	0.5992	0.0022	0.0033	4,185,891	G	2	381	6.0
767	11/06/85	82.83	701.48	2.2470	(41.6)	1.5024	0.0053	13.9929	0.03636	0.06163	0.5993	0.0022	0.0033	4,191,834	G	2	381	6.1
768	11/06/85	73.82	705.37	2.3145	(98.6)	3.5596	0.0057	21.8398	0.05260	0.09626	0.5986	0.0018	0.0033	6,609,960	G	2	384	-2.1
769	11/06/85	73.75	704.87	2.3130	(98.6)	3.5585	0.0058	21.8264	0.05258	0.09618	0.5985	0.0018	0.0033	6,606,983	G	2	383	-2.1
770	11/06/85	73.73	705.34	2.3149	(98.7)	3.5611	0.0057	21.8425	0.05260	0.09624	0.5985	0.0018	0.0033	6,611,547	G	2	384	-2.2
771	11/06/85	73.78	705.80	2.3162	(98.7)	3.5638	0.0057	21.8564	0.05260	0.09632	0.5985	0.0018	0.0033	6,614,843	G	2	384	-2.1
772	11/06/85	70.14	701.63	2.3250	(156.7)	5.6554	0.0064	27.5953	0.05502	0.12107	0.5985	0.0016	0.0033	8,393,823	G	3	382	-5.4
773	11/06/85	70.08	702.22	2.3275	(156.9)	5.6622	0.0064	27.6228	0.05505	0.12116	0.5984	0.0016	0.0033	8,401,942	G	3	383	-5.4
774	11/06/85	70.07	702.84	2.3298	(157.0)	5.6681	0.0065	27.6483	0.05505	0.12126	0.5983	0.0016	0.0033	8,409,045	G	3	383	-5.4
775	11/06/85	70.04	703.31	2.3317	(157.1)	5.6710	0.0064	27.6686	0.05506	0.12134	0.5984	0.0016	0.0033	8,414,825	G	3	383	-5.5
776	11/06/85	68.72	701.87	2.3349	(190.6)	6.8776	0.0068	30.5267	0.06389	0.13875	0.5989	0.0016	0.0034	9,300,091	G	2	383	-6.6
777	11/06/85	68.69	702.45	2.3372	(190.7)	6.8827	0.0069	30.5549	0.06391	0.13886	0.5989	0.0016	0.0034	9,308,167	G	2	383	-6.7
778	11/06/85	68.67	703.01	2.3394	(190.9)	6.8888	0.0068	30.5815	0.06393	0.13896	0.5989	0.0016	0.0034	9,315,663	G	2	383	-6.7
779	11/06/85	68.61	703.08	2.3400	(190.8)	6.8876	0.0069	30.5877	0.06397	0.13896	0.5990	0.0016	0.0034	9,318,123	G	2	383	-6.8

Table 29G. Orifice Discharge Coefficient Values for Orifice Plate FE-7/8-8B Mounted in Meter Tube PE-8ABC

Orifice Diameter = 0.6234 Inches-- Tube Diameter = 6.0829 Inches, Beta Ratio = 0.10248

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
889	11/19/85	82.20	711.57	2.2795	(49.9)	1.8026	0.0061	0.24598	0.00029	0.00071	0.5942	0.0015	0.0027	73,635	G 2	386	2.6
890	11/19/85	82.89	712.51	2.2788	(50.0)	1.8040	0.0058	0.24612	0.00029	0.00072	0.5944	0.0014	0.0027	73,603	G 2	386	3.2
891	11/19/85	83.57	713.63	2.2787	(50.1)	1.8089	0.0057	0.24629	0.00029	0.00072	0.5940	0.0014	0.0027	73,583	G 2	387	3.8
892	11/19/85	83.99	714.80	2.2804	(50.1)	1.8066	0.0059	0.24656	0.00029	0.00072	0.5948	0.0015	0.0027	73,613	G 2	388	4.3
893	11/19/85	86.12	718.16	2.2795	(103.1)	3.7212	0.0061	0.35511	0.00063	0.00109	0.5967	0.0014	0.0028	105,695	G 1	389	6.3
894	11/19/85	86.61	720.63	2.2845	(103.4)	3.7329	0.0055	0.35607	0.00063	0.00109	0.5967	0.0014	0.0028	105,876	G 1	391	6.9
895	11/19/85	87.11	722.86	2.2893	(103.7)	3.7416	0.0050	0.35697	0.00063	0.00110	0.5969	0.0014	0.0028	106,045	G 1	392	7.4
896	11/19/85	87.67	725.20	2.2941	(103.8)	3.7475	0.0075	0.35790	0.00063	0.00110	0.5973	0.0015	0.0028	106,213	G 1	393	8.0
897	11/19/85	85.19	733.11	2.3368	(6.9)	0.2505	0.0021	0.09297	0.00016	0.00028	0.5952	0.0028	0.0028	27,637	G 1	398	4.8
898	11/19/85	84.56	734.04	2.3438	(7.0)	0.2511	0.0018	0.09315	0.00016	0.00028	0.5949	0.0025	0.0027	27,709	G 1	398	4.4
899	11/19/85	84.09	735.04	2.3501	(6.9)	0.2501	0.0019	0.09334	0.00016	0.00028	0.5964	0.0026	0.0027	27,775	G 1	399	4.0
900	11/19/85	83.61	736.13	2.3568	(6.9)	0.2502	0.0019	0.09354	0.00016	0.00028	0.5967	0.0026	0.0027	27,845	G 1	399	3.6
901	11/19/85	87.76	734.14	2.3252	(166.2)	5.9970	0.0051	0.45542	0.00065	0.00140	0.5964	0.0012	0.0028	134,947	G 2	398	7.4
902	11/19/85	88.73	734.99	2.3224	(166.3)	6.0030	0.0053	0.45542	0.00065	0.00141	0.5965	0.0012	0.0028	134,775	G 2	399	8.2
903	11/19/85	89.39	735.80	2.3213	(166.4)	6.0061	0.0052	0.45553	0.00065	0.00141	0.5966	0.0012	0.0028	134,688	G 2	399	8.9
904	11/19/85	89.77	736.65	2.3221	(166.5)	6.0098	0.0056	0.45580	0.00065	0.00142	0.5967	0.0012	0.0028	134,689	G 2	400	9.3
905	11/19/85	90.94	737.78	2.3184	(219.0)	7.9050	0.0053	0.52243	0.00068	0.00162	0.5964	0.0011	0.0028	154,141	G 2	400	11.2
906	11/19/85	90.93	739.15	2.3244	(219.3)	7.9142	0.0046	0.52351	0.00068	0.00162	0.5965	0.0011	0.0028	154,425	G 2	401	11.3
907	11/19/85	90.83	740.20	2.3285	(219.4)	7.9180	0.0053	0.52431	0.00068	0.00162	0.5968	0.0011	0.0028	154,652	G 2	401	11.3
908	11/19/85	90.77	741.40	2.3330	(219.7)	7.9303	0.0050	0.52523	0.00068	0.00162	0.5968	0.0011	0.0028	154,908	G 2	402	11.2

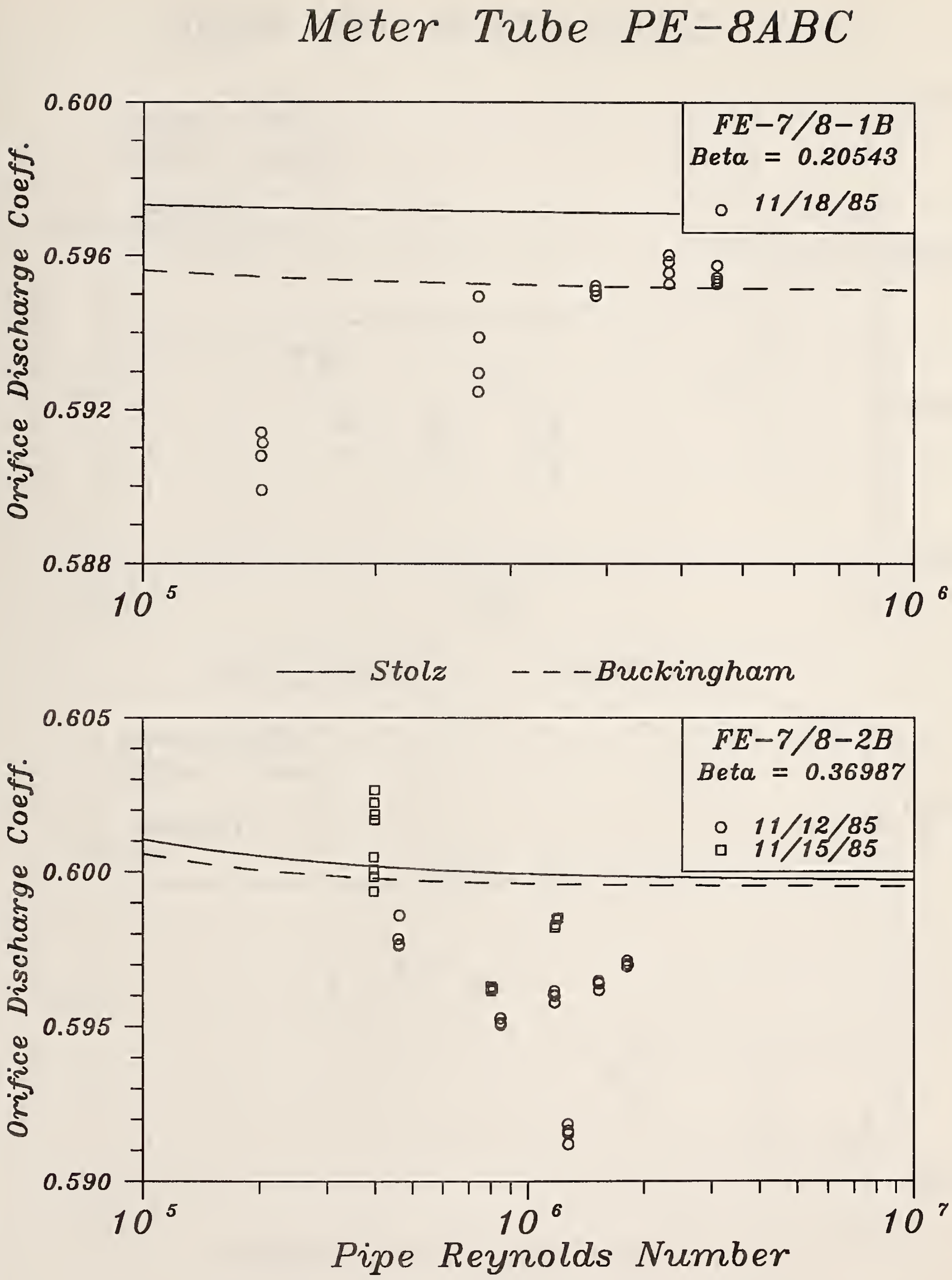


Figure 11A. Discharge coefficient/Reynolds number plots, PE-8ABC, 6-inch meter tube, 7 orifice plates.

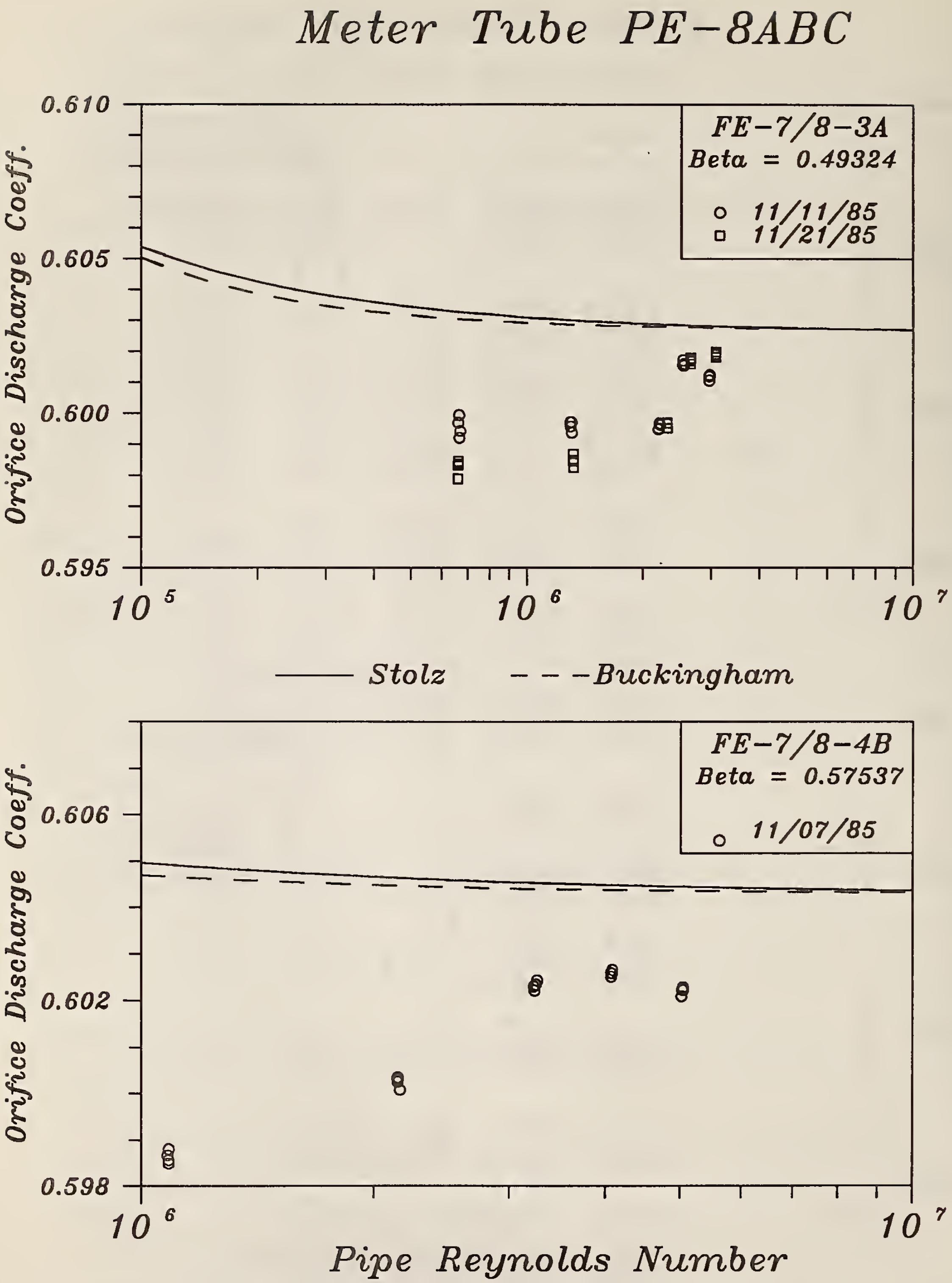


Figure 11B. Discharge coefficient/Reynolds number plots, PE-8ABC, 6-inch meter tube, 7 orifice plates.

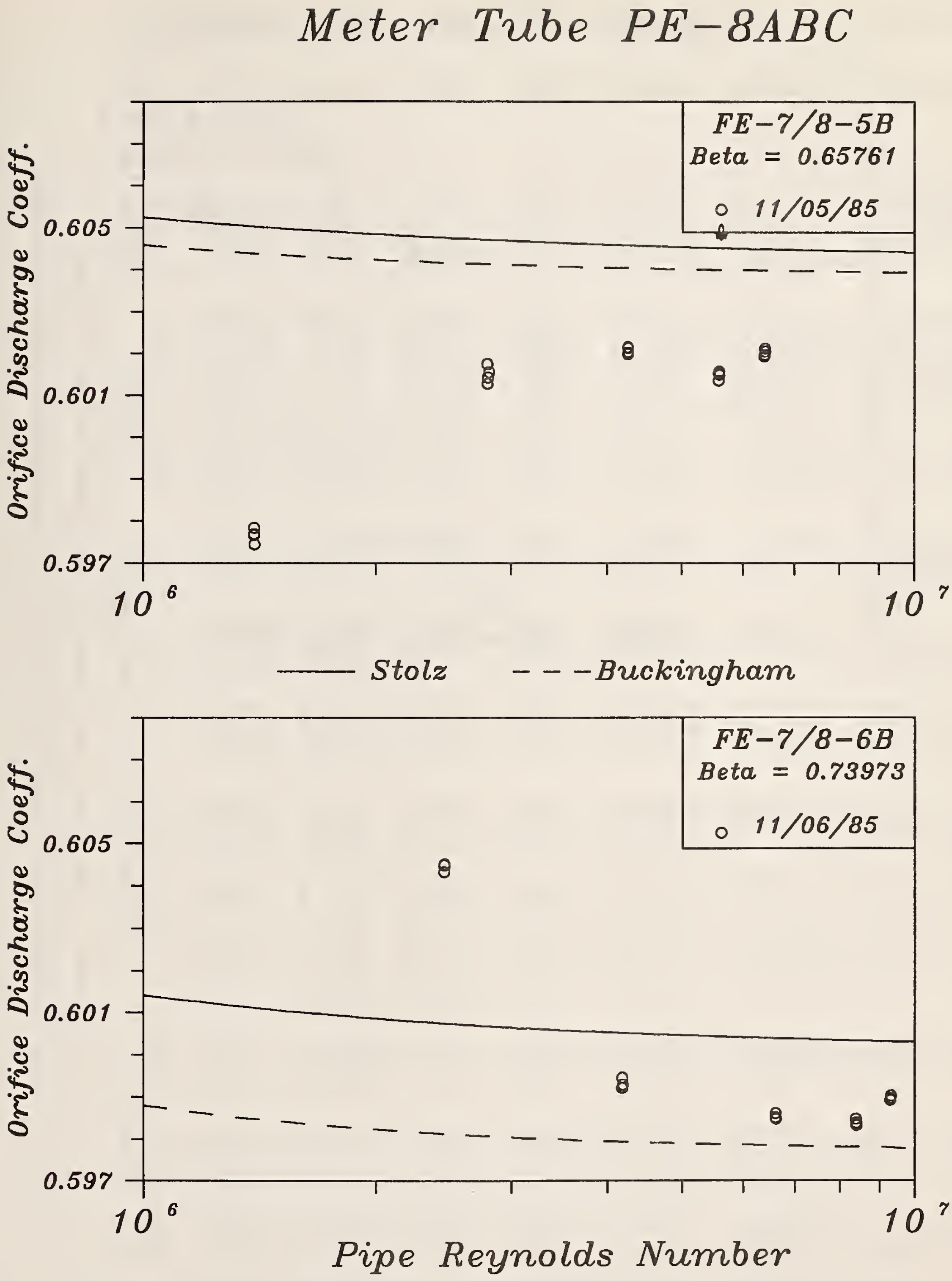


Figure 11C. Discharge coefficient/Reynolds number plots, PE-8ABC, 6-inch meter tube, 7 orifice plates.

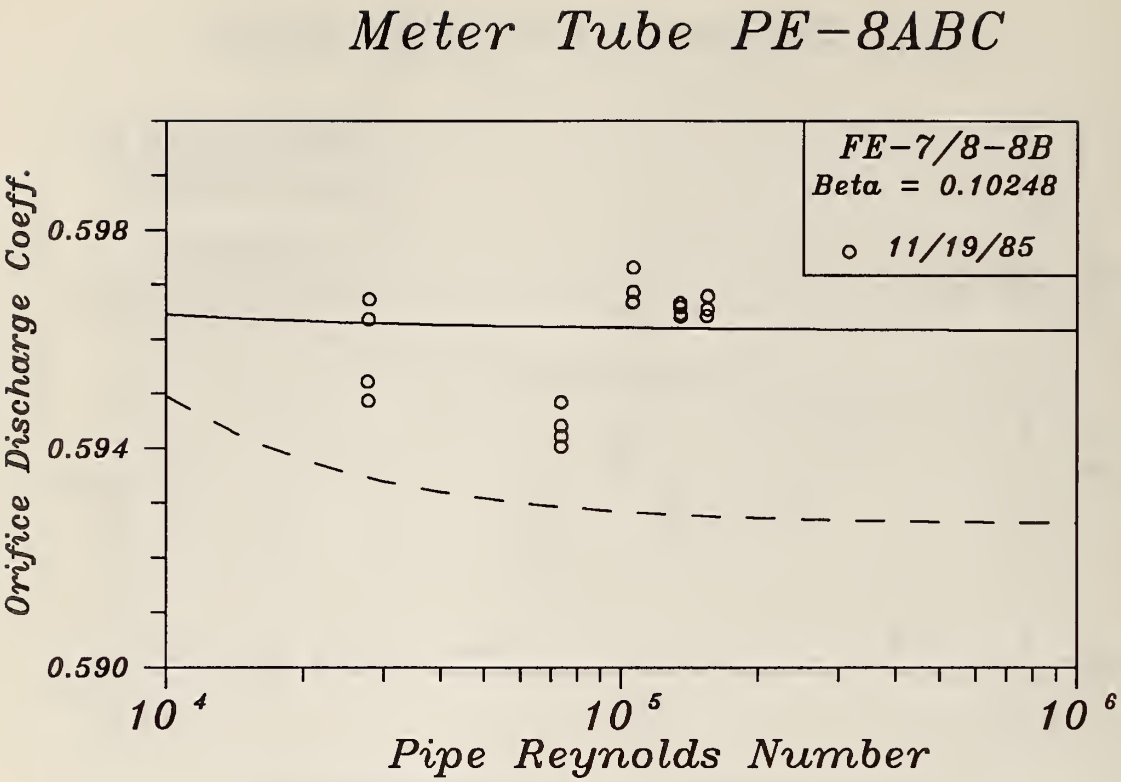


Figure 11D. Discharge coefficient/Reynolds number plots, PE-8ABC, 6-inch meter tube, 7 orifice plates.

Table 30A. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-1B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 1.9983 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.19819

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/	Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
230	08/21/85	78.64	627.13	2.0884	(55.2)	1.9932	0.0069	2.54778	0.00504	0.00775	0.5947	0.0018	0.0026	462,566	A	1	341	3.0
231	08/21/85	78.66	625.14	2.0811	(55.0)	1.9835	0.0083	2.53908	0.00507	0.00772	0.5951	0.0020	0.0026	461,120	A	1	340	3.1
232	08/21/85	78.67	623.43	2.0749	(54.8)	1.9766	0.0102	2.53180	0.00503	0.00770	0.5953	0.0022	0.0026	459,909	A	1	339	3.2
233	08/21/85	78.59	622.63	2.0724	(54.8)	1.9794	0.0068	2.52880	0.00502	0.00769	0.5946	0.0018	0.0026	459,468	A	1	338	3.1
234	08/21/85	77.79	621.63	2.0715	(219.2)	7.9101	0.0081	5.06558	0.01179	0.02350	0.5947	0.0017	0.0035	921,337	A	1	338	2.3
235	08/21/85	77.68	623.05	2.0772	(219.6)	7.9246	0.0082	5.07859	0.01180	0.02355	0.5949	0.0017	0.0035	923,634	A	1	339	2.2
236	08/21/85	77.70	625.11	2.0845	(220.4)	7.9557	0.0075	5.09584	0.01185	0.02363	0.5947	0.0017	0.0035	926,455	A	1	340	2.2
237	08/21/85	77.30	627.62	2.0958	(220.6)	7.9611	0.0337	5.12019	0.01182	0.02371	0.5957	0.0021	0.0035	931,002	A	1	341	1.8
238	08/21/85	79.92	636.72	2.1131	(100.8)	3.6388	0.0069	3.46820	0.00515	0.01056	0.5952	0.0014	0.0026	627,571	A	3	346	4.1
239	08/21/85	80.16	637.53	2.1148	(100.8)	3.6381	0.0083	3.47183	0.00515	0.01058	0.5957	0.0015	0.0026	627,959	A	3	347	4.2
240	08/21/85	79.97	638.09	2.1178	(101.1)	3.6478	0.0066	3.47586	0.00515	0.01058	0.5952	0.0014	0.0026	628,785	A	3	347	4.1
241	08/21/85	79.86	638.54	2.1201	(101.1)	3.6471	0.0068	3.47881	0.00515	0.01059	0.5954	0.0014	0.0026	629,366	A	3	347	4.0
244	08/21/85	78.04	631.76	2.1025	(144.3)	5.2067	0.0154	4.14598	0.00546	0.01243	0.5961	0.0015	0.0025	752,665	A	3	343	2.4
245	08/21/85	77.02	630.85	2.1045	(144.2)	5.2026	0.0075	4.14473	0.00546	0.01237	0.5958	0.0013	0.0025	753,548	A	3	343	1.4
246	08/21/85	76.59	630.63	2.1060	(144.2)	5.2030	0.0076	4.14519	0.00546	0.01234	0.5957	0.0013	0.0025	754,068	A	3	342	1.0
247	08/21/85	76.66	630.52	2.1052	(143.4)	5.1772	0.0259	4.14422	0.00546	0.01234	0.5971	0.0020	0.0025	753,841	A	3	342	1.1
248	08/22/85	73.37	643.33	2.1801	(13.5)	0.4875	0.0021	1.28613	0.00194	0.00376	0.5944	0.0018	0.0025	234,349	A	1	349	2.3
249	08/22/85	73.74	644.59	2.1827	(13.5)	0.4889	0.0020	1.28876	0.00194	0.00377	0.5945	0.0018	0.0025	234,668	A	1	349	2.4
250	08/22/85	75.34	628.11	2.1131	(13.1)	0.4711	0.0041	1.25362	0.00194	0.00368	0.5987	0.0029	0.0025	228,422	A	1	341	2.7
251	08/22/85	75.71	624.75	2.0989	(13.1)	0.4730	0.0022	1.24627	0.00196	0.00366	0.5960	0.0019	0.0025	227,097	A	1	339	2.9
252	08/22/85	76.14	621.44	2.0846	(13.0)	0.4696	0.0025	1.23905	0.00193	0.00364	0.5967	0.0021	0.0025	225,773	A	1	337	3.1
253	08/22/85	87.71	615.65	2.0037	(20.2)	0.7305	0.0021	1.53756	0.00202	0.00453	0.6053	0.0015	0.0026	276,366	A	2	334	2.5
255	08/22/85	82.69	605.19	1.9913	(19.9)	0.7190	0.0022	1.50999	0.00201	0.00444	0.6011	0.0016	0.0026	273,609	A	2	328	2.3
256	08/22/85	82.58	604.76	1.9903	(19.9)	0.7183	0.0023	1.50836	0.00201	0.00444	0.6009	0.0016	0.0026	273,369	A	2	328	2.5
257	08/22/85	82.57	604.37	1.9890	(19.6)	0.7064	0.0069	1.50724	0.00201	0.00444	0.6057	0.0032	0.0026	273,186	A	2	328	2.5
258	08/22/85	82.68	603.92	1.9869	(19.9)	0.7176	0.0022	1.50584	0.00201	0.00444	0.6007	0.0016	0.0026	272,913	A	2	328	2.7
260	08/23/85	81.03	598.60	1.9733	(19.7)	0.7122	0.0016	1.48666	0.00228	0.00444	0.5974	0.0016	0.0026	270,803	A	2	325	4.7
261	08/23/85	80.44	597.65	1.9728	(19.7)	0.7111	0.0016	1.48521	0.00228	0.00442	0.5973	0.0016	0.0026	270,786	A	2	324	4.2
262	08/23/85	79.87	597.02	1.9733	(19.7)	0.7107	0.0014	1.48455	0.00228	0.01220	0.5972	0.0015	0.0057	270,888	A	2	324	3.8
263	08/23/85	79.56	596.43	1.9726	(19.7)	0.7097	0.0015	1.48313	0.00228	0.00440	0.5972	0.0016	0.0026	270,775	A	2	324	3.6
264	08/23/85	79.62	594.04	1.9637	(19.3)	0.6954	0.0069	1.47642	0.00227	0.00438	0.6019	0.0033	0.0026	269,643	A	2	322	3.8
265	08/23/85	79.32	593.66	1.9638	(19.6)	0.7070	0.0015	1.47590	0.00227	0.00438	0.5967	0.0015	0.0026	269,665	A	2	322	3.6
266	08/23/85	79.18	593.35	1.9634	(19.5)	0.7039	0.0036	1.47520	0.00227	0.00437	0.5978	0.0021	0.0026	269,600	A	2	322	3.6
267	08/23/85	79.10	593.10	1.9629	(19.2)	0.6943	0.0069	1.47447	0.00227	0.00437	0.6017	0.0033	0.0026	269,503	A	2	322	3.6

Table 30A. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-1B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 1.9983 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.19819

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total	Rand.	Syst. (pounds/second)	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
270	08/26/85	98.08	591.43	1.8809	(8.1)	0.2920	0.0016	0.92950	0.00105	0.00304	0.5973	0.0021	0.0028	165,489	A 3	322	21.4
271	08/26/85	97.95	590.44	1.8780	(8.1)	0.2913	0.0016	0.92811	0.00105	0.00303	0.5976	0.0021	0.0028	165,291	A 3	321	21.2
272	08/26/85	97.54	589.82	1.8777	(8.1)	0.2908	0.0017	0.92761	0.00105	0.00302	0.5979	0.0021	0.0028	165,303	A 3	321	20.9
273	08/26/85	97.00	589.52	1.8790	(8.1)	0.2905	0.0016	0.92757	0.00105	0.00302	0.5979	0.0021	0.0028	165,416	A 3	321	20.5
274	08/26/85	96.44	577.02	1.8365	(19.0)	0.6867	0.0021	1.40626	0.00187	0.00454	0.5964	0.0016	0.0028	251,372	A 2	314	19.9
275	08/26/85	96.12	575.65	1.8331	(19.0)	0.6850	0.0019	1.40349	0.00187	0.00452	0.5965	0.0016	0.0028	251,025	A 2	313	19.5
276	08/26/85	95.71	574.29	1.8303	(18.8)	0.6799	0.0036	1.40092	0.00186	0.00450	0.5981	0.0021	0.0028	250,744	A 2	312	19.0
277	08/26/85	95.46	573.24	1.8277	(18.9)	0.6820	0.0019	1.39868	0.00187	0.00449	0.5966	0.0016	0.0027	250,457	A 2	311	18.8
279	08/27/85	95.73	623.04	2.0023	(8.5)	0.3083	0.0016	0.98433	0.00113	0.00318	0.5967	0.0019	0.0027	175,309	A 3	339	19.5
280	08/27/85	95.46	622.83	2.0029	(8.5)	0.3070	0.0015	0.98409	0.00113	0.00318	0.5977	0.0019	0.0027	175,330	A 3	339	19.4
281	08/27/85	95.22	622.38	2.0025	(8.5)	0.3069	0.0015	0.98365	0.00113	0.00318	0.5976	0.0019	0.0027	175,316	A 3	339	19.2
282	08/27/85	95.23	622.11	2.0015	(8.5)	0.3070	0.0015	0.98308	0.00113	0.00318	0.5974	0.0019	0.0027	175,219	A 3	338	19.2

Table 30B. Orifice Discharge Coefficient Values for Orifice Plate FE-9/O-2A Mounted in Meter Tube FE-9ABC

Orifice Diameter = 3.7480 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.37172

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
114	08/08/85	85.15	557.35	1.8112	(8.5)	0.3081	0.0014	3.32707	0.00429	0.01039	0.5978	0.0019	0.0027	606,121	A 2	303	9.5
115	08/08/85	83.96	557.41	1.8166	(8.5)	0.3078	0.0015	3.33258	0.00430	0.01034	0.5982	0.0019	0.0026	608,074	A 2	303	8.4
116	08/08/85	82.71	557.45	1.8221	(8.5)	0.3079	0.0015	3.33813	0.00430	0.01030	0.5982	0.0020	0.0026	610,078	A 2	303	7.2
117	08/08/85	81.38	557.40	1.8278	(8.5)	0.3072	0.0014	3.34303	0.00431	0.01025	0.5989	0.0019	0.0026	612,049	A 2	303	6.0
118	08/08/85	73.78	556.76	1.8591	(15.4)	0.5559	0.0016	4.53381	0.00886	0.02084	0.5987	0.0018	0.0035	838,584	A 1	303	-0.8
119	08/08/85	73.31	556.74	1.8613	(15.4)	0.5557	0.0016	4.53656	0.00886	0.02081	0.5988	0.0018	0.0035	839,573	A 1	303	-1.2
120	08/08/85	72.92	556.64	1.8627	(15.4)	0.5551	0.0015	4.53796	0.00887	0.02079	0.5991	0.0018	0.0035	840,275	A 1	303	-1.6
121	08/08/85	72.50	556.55	1.8644	(15.4)	0.5559	0.0015	4.53971	0.00887	0.02077	0.5986	0.0018	0.0035	841,090	A 1	303	-2.0
122	08/08/85	71.71	554.05	1.8591	(60.5)	2.1834	0.0035	9.01939	0.02287	0.04157	0.6006	0.0019	0.0035	1,673,505	A 1	301	-2.6
123	08/08/85	71.77	554.11	1.8591	(60.5)	2.1839	0.0035	9.02012	0.02287	0.04158	0.6006	0.0019	0.0035	1,673,506	A 1	301	-2.5
124	08/08/85	71.79	554.31	1.8598	(60.6)	2.1856	0.0034	9.02292	0.02288	0.04160	0.6005	0.0019	0.0035	1,673,933	A 1	302	-2.5
125	08/08/85	71.81	554.55	1.8605	(60.6)	2.1858	0.0034	9.02645	0.02288	0.04162	0.6005	0.0019	0.0035	1,674,465	A 1	302	-2.5
126	08/09/85	74.51	575.20	1.9251	(98.2)	3.5455	0.0097	11.6973	0.02376	0.05049	0.6004	0.0018	0.0033	2,155,330	A 2	313	-0.1
127	08/09/85	74.25	574.88	1.9252	(98.3)	3.5464	0.0097	11.6949	0.02376	0.05043	0.6002	0.0018	0.0033	2,155,741	A 2	313	-0.3
128	08/09/85	73.93	574.43	1.9252	(98.2)	3.5428	0.0097	11.6905	0.02376	0.05036	0.6003	0.0018	0.0033	2,155,981	A 2	313	-0.6
129	08/09/85	73.67	573.95	1.9244	(98.1)	3.5394	0.0096	11.6835	0.02375	0.05028	0.6003	0.0018	0.0033	2,155,733	A 2	312	-0.8
130	08/09/85	72.12	569.49	1.9154	(140.4)	5.0683	0.0100	13.9512	0.02537	0.06414	0.6001	0.0016	0.0035	2,581,260	A 2	310	-2.3
131	08/09/85	71.93	569.04	1.9147	(140.2)	5.0613	0.0100	13.9424	0.02536	0.06407	0.6003	0.0016	0.0035	2,580,449	A 2	310	-2.5
132	08/09/85	71.81	568.49	1.9132	(140.2)	5.0599	0.0098	13.9301	0.02536	0.06399	0.6001	0.0016	0.0035	2,578,801	A 2	309	-2.6
133	08/09/85	71.80	567.96	1.9114	(140.0)	5.0512	0.0100	13.9173	0.02534	0.06393	0.6003	0.0017	0.0035	2,576,654	A 2	309	-2.6
134	08/09/85	71.32	561.15	1.8879	(188.2)	6.7929	0.0102	16.0471	0.02559	0.06986	0.6002	0.0015	0.0034	2,976,084	A 3	306	-3.0
135	08/09/85	71.74	560.75	1.8845	(188.1)	6.7904	0.0101	16.0268	0.02557	0.06987	0.6001	0.0015	0.0034	2,970,858	A 3	305	-2.6
136	08/09/85	72.24	560.00	1.8794	(187.8)	6.7785	0.0102	15.9935	0.02553	0.06985	0.6002	0.0015	0.0034	2,963,012	A 3	305	-2.1
137	08/09/85	72.54	559.34	1.8756	(187.6)	6.7725	0.0104	15.9681	0.02551	0.06981	0.6001	0.0015	0.0034	2,957,442	A 3	305	-1.8
357	09/04/85	86.23	641.56	2.1122	(70.2)	2.5334	0.0085	10.3475	0.02324	0.04973	0.6000	0.0019	0.0036	1,858,471	A 1	349	10.2
358	09/04/85	86.95	640.66	2.1053	(70.1)	2.5292	0.0086	10.3225	0.02320	0.04973	0.6000	0.0019	0.0036	1,852,558	A 1	349	10.9
359	09/04/85	87.61	639.83	2.0989	(70.0)	2.5272	0.0085	10.2998	0.02316	0.04972	0.5998	0.0019	0.0036	1,847,205	A 1	348	11.5
360	09/04/85	88.22	638.76	2.0920	(69.9)	2.5213	0.0085	10.2738	0.02312	0.04969	0.6000	0.0019	0.0036	1,841,421	A 1	348	12.1
361	09/04/85	85.99	612.70	2.0095	(104.7)	3.7771	0.0087	12.3308	0.02285	0.05522	0.6001	0.0017	0.0034	2,225,415	A 2	333	10.3
362	09/04/85	86.20	610.48	2.0006	(104.3)	3.7639	0.0088	12.2810	0.02277	0.05505	0.6000	0.0017	0.0034	2,216,566	A 2	332	10.5
363	09/04/85	86.30	608.78	1.9941	(104.0)	3.7519	0.0086	12.2436	0.02273	0.05490	0.6001	0.0017	0.0034	2,210,090	A 2	331	10.6
364	09/04/85	86.50	607.10	1.9850	(103.7)	3.7409	0.0087	12.1985	0.02265	0.05474	0.6002	0.0017	0.0034	2,202,565	A 2	330	10.8

Table 30B. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-2A Mounted in Meter Tube FE-9ABC

Orifice Diameter = 3.7480 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.37172

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
365	09/04/85	83.49	599.81	1.9740	(147.8)	5.3354	0.0088	14.5284	0.02392	0.06916	0.5999	0.0015	0.0036	2,636,471	A 2	327	8.0
366	09/04/85	83.50	598.91	1.9708	(147.6)	5.3253	0.0090	14.5061	0.02390	0.06906	0.6000	0.0015	0.0036	2,632,723	A 2	326	8.0
367	09/04/85	83.45	598.06	1.9688	(147.3)	5.3167	0.0090	14.4877	0.02388	0.06896	0.6001	0.0015	0.0036	2,629,697	A 2	326	8.0
368	09/04/85	83.36	597.36	1.9667	(147.1)	5.3101	0.0090	14.4717	0.02387	0.06887	0.6001	0.0015	0.0036	2,627,351	A 2	325	7.9
369	09/04/85	80.44	590.16	1.9543	(197.9)	7.1435	0.0091	16.7375	0.02407	0.07505	0.5999	0.0014	0.0034	3,053,754	A 3	321	5.3
370	09/04/85	80.40	589.53	1.9523	(197.6)	7.1330	0.0093	16.7190	0.02405	0.07496	0.6000	0.0014	0.0034	3,050,823	A 3	321	5.3
371	09/04/85	80.49	585.42	1.9396	(196.3)	7.0839	0.0092	16.6038	0.02395	0.07449	0.5999	0.0014	0.0034	3,031,543	A 3	319	5.5
372	09/04/85	80.44	585.06	1.9385	(196.1)	7.0776	0.0093	16.5938	0.02395	0.07444	0.6000	0.0014	0.0034	3,030,066	A 3	319	5.4

Table 30C. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-2B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 3.7480 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.37172

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.		-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand.	Syst.	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
34	08/02/85	77.23	601.68	1.9974	(9.3)	0.3351	0.0026	3.63638	0.00358	0.01087	0.5967	0.0026	0.0025	665,247	A	2	327	1.7
35	08/02/85	77.19	597.14	1.9817	(9.2)	0.3324	0.0027	3.60819	0.00352	0.01079	0.5968	0.0027	0.0025	660,517	A	2	324	1.6
36	08/02/85	77.11	593.89	1.9704	(9.2)	0.3309	0.0028	3.58811	0.00357	0.01072	0.5965	0.0027	0.0025	657,228	A	2	322	1.6
37	08/02/85	76.96	590.48	1.9589	(9.1)	0.3295	0.0026	3.56718	0.00350	0.01066	0.5961	0.0027	0.0025	653,864	A	2	321	1.5
38	08/02/85	76.55	579.59	1.9230	(16.1)	0.5827	0.0028	4.70552	0.00838	0.02178	0.5967	0.0020	0.0035	864,272	A	1	315	1.5
39	08/02/85	77.11	578.47	1.9163	(16.1)	0.5814	0.0029	4.69271	0.00837	0.02176	0.5968	0.0021	0.0035	861,425	A	1	314	2.0
40	08/02/85	77.67	577.31	1.9096	(16.1)	0.5808	0.0027	4.67963	0.00836	0.02174	0.5965	0.0020	0.0035	858,549	A	1	314	2.5
41	08/02/85	78.04	576.10	1.9037	(16.0)	0.5789	0.0028	4.66706	0.00834	0.02171	0.5968	0.0021	0.0035	855,969	A	1	313	2.9
42	08/02/85	79.57	578.64	1.9053	(36.0)	1.3004	0.0030	7.01376	0.00888	0.02904	0.5980	0.0014	0.0032	1,283,425	A	2	315	4.4
43	08/02/85	79.57	579.68	1.9090	(36.1)	1.3019	0.0030	7.02651	0.00888	0.02909	0.5981	0.0014	0.0032	1,285,553	A	2	315	4.4
44	08/02/85	79.55	580.56	1.9122	(36.2)	1.3047	0.0029	7.03780	0.00888	0.02914	0.5979	0.0014	0.0032	1,287,486	A	2	316	4.4
45	08/02/85	79.46	579.57	1.9091	(36.1)	1.3017	0.0030	7.02583	0.00931	0.02908	0.5981	0.0015	0.0032	1,285,638	A	2	315	4.3
46	08/02/85	76.56	564.81	1.8702	(96.7)	3.4915	0.0102	11.4202	0.01940	0.04965	0.5993	0.0017	0.0034	2,102,400	A	2	307	1.9
47	08/02/85	75.98	563.37	1.8678	(96.5)	3.4833	0.0102	11.3977	0.01937	0.04946	0.5992	0.0017	0.0034	2,100,314	A	2	306	1.3
48	08/02/85	75.69	561.97	1.8641	(96.2)	3.4736	0.0102	11.3727	0.01934	0.04931	0.5993	0.0017	0.0034	2,096,963	A	2	306	1.1
49	08/02/85	75.21	560.46	1.8609	(96.0)	3.4651	0.0102	11.3473	0.01928	0.04912	0.5992	0.0017	0.0034	2,094,071	A	2	305	0.7
50	08/02/85	74.30	552.73	1.8374	(136.6)	4.9315	0.0103	13.4540	0.02061	0.06233	0.5990	0.0015	0.0036	2,489,165	A	2	301	-0.2
51	08/02/85	73.94	547.80	1.8216	(135.4)	4.8868	0.0102	13.3348	0.02052	0.06172	0.5990	0.0015	0.0036	2,470,124	A	2	298	-0.5
52	08/02/85	73.93	546.41	1.8167	(135.0)	4.8732	0.0104	13.2996	0.02047	0.06156	0.5991	0.0015	0.0036	2,464,127	A	2	297	-0.5
53	08/02/85	74.08	545.27	1.8119	(134.8)	4.8635	0.0103	13.2682	0.02042	0.06145	0.5990	0.0015	0.0036	2,458,273	A	2	297	-0.4
54	08/02/85	73.96	536.88	1.7828	(162.8)	5.8767	0.0105	14.4915	0.02666	0.06756	0.5998	0.0016	0.0036	2,688,973	A	1	292	-0.8
55	08/02/85	73.90	535.77	1.7791	(162.4)	5.8630	0.0105	14.4618	0.02660	0.06742	0.5999	0.0016	0.0036	2,684,098	A	1	292	-0.8
56	08/02/85	73.77	535.16	1.7775	(162.3)	5.8591	0.0103	14.4462	0.02656	0.06732	0.5997	0.0016	0.0036	2,681,950	A	1	291	-1.0
57	08/02/85	73.79	534.72	1.7758	(162.1)	5.8510	0.0107	14.4332	0.02655	0.06726	0.5999	0.0016	0.0036	2,679,626	A	1	291	-0.9

Table 30D. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-3B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 4.9976 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.49565

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
1	07/30/85	86.48	604.00	1.9601	(11.4)	0.4100	0.0019	7.26705	0.00987	0.03079	0.5990	0.0019	0.0033	1,313,441	A 2	328	10.6
2	07/30/85	86.52	603.56	1.9584	(11.4)	0.4100	0.0019	7.26143	0.00992	0.03077	0.5987	0.0019	0.0033	1,312,442	A 2	328	10.7
3	07/30/85	86.66	601.21	1.9496	(11.3)	0.4085	0.0020	7.23072	0.01009	0.03066	0.5987	0.0020	0.0033	1,307,116	A 2	327	10.8
4	07/30/85	86.73	597.70	1.9283	(11.2)	0.4053	0.0020	7.17209	0.00991	0.03041	0.5994	0.0020	0.0033	1,296,734	A 2	325	10.7
5	07/30/85	82.65	598.86	1.9589	(19.7)	0.7127	0.0020	9.62498	0.02263	0.04581	0.6019	0.0019	0.0036	1,749,626	A 1	326	7.1
6	07/30/85	82.57	594.71	1.9446	(19.6)	0.7077	0.0019	9.55605	0.02244	0.04548	0.6019	0.0019	0.0036	1,738,347	A 1	323	7.0
7	07/30/85	82.53	586.64	1.9157	(19.3)	0.6970	0.0020	9.41776	0.02249	0.04483	0.6022	0.0020	0.0036	1,715,563	A 1	319	7.1
8	07/30/85	82.52	583.62	1.9051	(19.2)	0.6940	0.0019	9.36797	0.02221	0.04460	0.6020	0.0020	0.0036	1,707,284	A 1	317	7.1
9	07/31/85	86.37	602.91	1.9548	(15.3)	0.5522	0.0015	8.43991	0.01443	0.03435	0.6002	0.0017	0.0032	1,525,472	A 3	328	10.4
10	07/31/85	86.07	601.76	1.9522	(15.3)	0.5509	0.0015	8.42594	0.01442	0.03426	0.6003	0.0018	0.0032	1,523,792	A 3	327	10.1
11	07/31/85	85.83	600.86	1.9502	(15.2)	0.5501	0.0016	8.41553	0.01441	0.03419	0.6003	0.0018	0.0032	1,522,579	A 3	326	9.9
12	07/31/85	85.81	600.05	1.9475	(15.2)	0.5495	0.0015	8.40351	0.01441	0.03414	0.6002	0.0018	0.0032	1,520,622	A 3	326	9.9
13	07/31/85	79.55	593.32	1.9529	(54.4)	1.9621	0.0051	15.9493	0.05778	0.07544	0.6018	0.0026	0.0036	2,912,220	A 1	323	3.8
14	07/31/85	80.02	592.63	1.9481	(54.3)	1.9591	0.0051	15.9201	0.05773	0.07542	0.6019	0.0026	0.0036	2,905,398	A 1	322	4.3
15	07/31/85	80.41	591.97	1.9440	(54.2)	1.9567	0.0051	15.8939	0.05769	0.07539	0.6019	0.0026	0.0036	2,899,448	A 1	322	4.6
16	07/31/85	80.55	591.31	1.9410	(54.2)	1.9543	0.0052	15.8720	0.05766	0.07532	0.6019	0.0026	0.0036	2,895,211	A 1	322	4.8
17	07/31/85	76.97	583.77	1.9312	(90.5)	3.2664	0.0053	20.4814	0.05922	0.09587	0.6021	0.0021	0.0036	3,757,689	A 2	318	1.7
18	07/31/85	76.99	582.96	1.9282	(90.4)	3.2633	0.0053	20.4514	0.05920	0.09574	0.6019	0.0022	0.0036	3,752,549	A 2	317	1.8
19	07/31/85	77.07	583.35	1.9282	(90.5)	3.2657	0.0058	20.4581	0.05989	0.09579	0.6019	0.0022	0.0036	3,752,961	A 2	318	1.8
20	07/31/85	77.32	592.82	1.9608	(92.0)	3.3206	0.0055	20.7980	0.05959	0.09742	0.6018	0.0021	0.0035	3,808,646	A 2	323	2.0
22	07/31/85	74.02	578.52	1.9244	(135.5)	4.8919	0.0055	25.0514	0.06634	0.11639	0.6025	0.0020	0.0035	4,617,478	A 2	315	-0.9
23	07/31/85	74.04	578.69	1.9250	(135.6)	4.8943	0.0055	25.0583	0.06634	0.11643	0.6024	0.0020	0.0035	4,618,509	A 2	315	-0.9
24	07/31/85	74.05	578.90	1.9257	(135.7)	4.8958	0.0056	25.0688	0.06635	0.11648	0.6025	0.0020	0.0035	4,620,259	A 2	315	-0.9
25	07/31/85	74.05	579.14	1.9265	(135.7)	4.8970	0.0055	25.0791	0.06635	0.11653	0.6025	0.0020	0.0035	4,621,962	A 2	315	-0.9
26	08/01/85	77.63	596.53	1.9728	(11.2)	0.4042	0.0017	7.24832	0.01468	0.02977	0.5999	0.0021	0.0032	1,326,676	A 2	324	2.5
27	08/01/85	77.78	595.04	1.9666	(11.2)	0.4032	0.0017	7.22811	0.01467	0.02970	0.5998	0.0021	0.0032	1,323,011	A 2	323	2.6
28	08/01/85	77.62	593.19	1.9607	(11.1)	0.4019	0.0017	7.20607	0.01467	0.02960	0.5999	0.0021	0.0032	1,319,625	A 2	322	2.5
29	08/01/85	77.48	590.91	1.9533	(11.1)	0.4002	0.0017	7.17861	0.01465	0.02948	0.6000	0.0021	0.0032	1,315,290	A 2	321	2.4
30	08/01/85	69.94	564.96	1.8960	(187.0)	6.7478	0.0056	29.2176	0.04582	0.13384	0.6024	0.0015	0.0035	5,428,580	A 3	308	-4.5
31	08/01/85	70.38	563.69	1.8893	(186.5)	6.7323	0.0052	29.1305	0.04575	0.13364	0.6024	0.0015	0.0035	5,410,268	A 3	307	-4.1
32	08/01/85	70.68	562.47	1.8835	(186.1)	6.7182	0.0052	29.0536	0.04570	0.13342	0.6023	0.0015	0.0035	5,394,890	A 3	307	-3.8
33	08/01/85	70.96	561.16	1.8774	(185.6)	6.6980	0.0054	28.9722	0.04562	0.13318	0.6025	0.0015	0.0035	5,378,793	A 3	306	-3.5

Table 30D. Orifice Discharge Coefficient Values for Orifice Plate FE-9/O-3B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 4.9976 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.49565

Run	Date	------- Orifice	-------		----- Diff. Press.	-----		---- Mass Flow Rate	----		---- Discharge Coefficient	----		Pipe Rey.	Gas/	-- Throat	--
No.		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.	Number	Num. Noz.	Press. (Psia)	Temp. (°F)°
330	08/30/85	85.16	586.62	1.9079	(19.3)	0.6981	0.0013	9.39761	0.02055	0.04512	0.6016	0.0018	0.0036	1,708,695	A 1	319	9.6
331	08/30/85	85.71	586.22	1.9036	(19.3)	0.6978	0.0013	9.38328	0.02053	0.04513	0.6015	0.0018	0.0036	1,704,951	A 1	319	10.1
332	08/30/85	85.82	586.01	1.9023	(19.3)	0.6975	0.0014	9.37848	0.02052	0.04512	0.6015	0.0018	0.0036	1,703,893	A 1	319	10.3
333	08/30/85	85.70	585.79	1.9021	(19.3)	0.6968	0.0014	9.37602	0.02051	0.04510	0.6017	0.0018	0.0036	1,703,775	A 1	319	10.1
334	08/30/85	84.09	584.34	1.9045	(24.3)	0.8757	0.0014	10.5221	0.02059	0.04835	0.6019	0.0017	0.0035	1,916,573	A 2	318	8.6
336	08/30/85	84.55	575.33	1.8704	(23.9)	0.8618	0.0014	10.3463	0.02037	0.04763	0.6021	0.0017	0.0035	1,885,927	A 2	313	9.1
337	08/30/85	84.75	574.30	1.8657	(23.8)	0.8601	0.0014	10.3240	0.02033	0.04756	0.6021	0.0017	0.0035	1,881,591	A 2	312	9.3
338	08/30/85	83.66	570.61	1.8578	(29.4)	1.0601	0.0014	11.4346	0.02063	0.05092	0.6019	0.0016	0.0034	2,088,161	A 2	311	8.5
339	08/30/85	83.54	570.00	1.8562	(29.3)	1.0590	0.0014	11.4235	0.02062	0.05085	0.6019	0.0016	0.0034	2,086,655	A 2	310	8.4
340	08/30/85	83.58	569.30	1.8535	(29.3)	1.0574	0.0014	11.4083	0.02061	0.05079	0.6020	0.0016	0.0034	2,083,984	A 2	310	8.4
341	08/30/85	83.53	568.65	1.8516	(29.3)	1.0566	0.0015	11.3955	0.02059	0.05073	0.6019	0.0016	0.0034	2,081,858	A 2	309	8.3
342	08/30/85	81.63	561.24	1.8342	(41.7)	1.5049	0.0052	13.5358	0.02184	0.06417	0.6018	0.0018	0.0036	2,481,527	A 2	305	6.6
343	08/30/85	81.93	560.70	1.8310	(41.7)	1.5039	0.0052	13.5171	0.02178	0.06414	0.6017	0.0018	0.0036	2,477,335	A 2	305	6.8
344	08/30/85	81.95	560.61	1.8306	(41.7)	1.5038	0.0052	13.5144	0.02178	0.06414	0.6017	0.0018	0.0036	2,476,802	A 2	305	6.9
345	08/30/85	81.91	560.44	1.8301	(41.6)	1.5028	0.0052	13.5106	0.02177	0.06411	0.6018	0.0018	0.0036	2,476,277	A 2	305	6.9
346	09/03/85	91.23	605.73	1.9735	(11.3)	0.4065	0.0010	7.29444	0.00885	0.03146	0.6017	0.0014	0.0033	1,309,048	A 2	330	15.4
347	09/03/85	91.26	605.86	1.9737	(11.3)	0.4061	0.0010	7.29581	0.00885	0.03147	0.6021	0.0014	0.0033	1,309,207	A 2	330	15.4
348	09/03/85	91.50	606.07	1.9734	(11.3)	0.4063	0.0010	7.29618	0.00885	0.03150	0.6020	0.0014	0.0033	1,308,849	A 2	330	15.6
349	09/03/85	91.45	606.10	1.9737	(11.3)	0.4063	0.0010	7.29647	0.00885	0.03150	0.6019	0.0014	0.0033	1,308,967	A 2	330	15.6
353	09/03/85	89.19	608.39	1.9927	(19.9)	0.7187	0.0011	9.77261	0.02035	0.04751	0.6033	0.0017	0.0037	1,757,529	A 1	331	13.5
354	09/03/85	88.70	609.25	1.9981	(20.0)	0.7201	0.0011	9.79350	0.02039	0.04754	0.6032	0.0017	0.0036	1,762,158	A 1	332	13.1
355	09/03/85	88.89	609.65	1.9986	(19.9)	0.7200	0.0011	9.79770	0.02040	0.04758	0.6034	0.0017	0.0036	1,762,389	A 1	332	13.2
356	09/03/85	89.48	610.16	1.9975	(20.0)	0.7214	0.0010	9.79921	0.02040	0.04767	0.6031	0.0017	0.0037	1,761,217	A 1	332	13.7

Table 30E. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-4A Mounted in Meter Tube FE-9ABC

Orifice Diameter = 5.7488 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.57015

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
138	08/09/85	71.90	560.25	1.8800	(10.0)	0.3608	0.0010	9.11898	0.02303	0.04204	0.6033	0.0021	0.0035	1,690,329	A 1	305	-2.5
139	08/09/85	71.70	559.16	1.8768	(10.0)	0.3601	0.0010	9.10279	0.02301	0.04194	0.6033	0.0021	0.0035	1,688,066	A 1	304	-2.7
140	08/09/85	71.48	558.68	1.8761	(10.0)	0.3598	0.0010	9.09680	0.02301	0.04188	0.6033	0.0021	0.0035	1,687,579	A 1	304	-2.9
141	08/09/85	71.24	558.02	1.8748	(10.0)	0.3594	0.0010	9.08804	0.02301	0.04181	0.6033	0.0021	0.0035	1,686,664	A 1	303	-3.1
142	08/09/85	71.54	554.23	1.8591	(22.3)	0.8063	0.0012	13.5436	0.02499	0.06220	0.6027	0.0016	0.0035	2,514,200	A 2	301	-2.8
143	08/09/85	71.68	554.33	1.8588	(22.3)	0.8058	0.0011	13.5437	0.02499	0.06222	0.6029	0.0016	0.0035	2,513,719	A 2	301	-2.6
144	08/09/85	71.57	554.61	1.8603	(22.3)	0.8061	0.0012	13.5522	0.02500	0.06224	0.6029	0.0016	0.0035	2,515,551	A 2	302	-2.7
145	08/09/85	71.83	554.79	1.8593	(22.3)	0.8066	0.0011	13.5511	0.02499	0.06228	0.6029	0.0016	0.0035	2,514,646	A 2	302	-2.5
146	08/09/85	71.61	551.48	1.8482	(46.3)	1.6712	0.0094	19.4464	0.03231	0.08966	0.6027	0.0023	0.0035	3,611,769	A 2	300	-2.9
147	08/09/85	71.47	551.60	1.8493	(46.3)	1.6710	0.0094	19.4542	0.03232	0.08966	0.6028	0.0023	0.0035	3,613,819	A 2	300	-3.0
148	08/09/85	71.45	551.80	1.8501	(46.3)	1.6714	0.0094	19.4621	0.03232	0.08969	0.6028	0.0023	0.0035	3,615,266	A 2	300	-3.0
149	08/09/85	71.48	551.92	1.8504	(46.3)	1.6725	0.0094	19.4656	0.03233	0.08971	0.6027	0.0023	0.0035	3,615,727	A 2	300	-3.0
150	08/12/85	70.67	588.54	1.9999	(105.7)	3.8159	0.0068	30.5906	0.04595	0.14043	0.6028	0.0015	0.0035	5,650,714	A 3	321	-3.8
151	08/12/85	70.72	588.09	1.9980	(105.7)	3.8139	0.0068	30.5681	0.04594	0.14035	0.6028	0.0015	0.0035	5,646,641	A 3	321	-3.7
152	08/12/85	70.73	587.30	1.9950	(105.5)	3.8081	0.0068	30.5217	0.04590	0.14014	0.6028	0.0015	0.0035	5,638,678	A 3	320	-3.7
153	08/12/85	70.81	586.55	1.9918	(105.4)	3.8026	0.0069	30.4788	0.04588	0.13999	0.6028	0.0015	0.0035	5,630,834	A 3	320	-3.6
182	08/14/85	69.19	544.17	1.8358	(143.5)	5.1788	0.0060	34.0711	0.05272	0.16348	0.6012	0.0015	0.0036	6,352,136	A 2	297	-4.8
183	08/14/85	69.42	543.37	1.8318	(143.3)	5.1725	0.0060	34.0089	0.05267	0.16331	0.6011	0.0015	0.0037	6,339,335	A 2	296	-4.6
184	08/14/85	69.59	542.58	1.8282	(143.1)	5.1647	0.0060	33.9502	0.05265	0.16312	0.6003	0.0015	0.0036	6,327,700	A 2	296	-4.4
185	08/14/85	69.74	541.70	1.8251	(142.8)	5.1548	0.0059	33.8899	0.05261	0.16292	0.6011	0.0015	0.0037	6,315,603	A 2	295	-4.2
186	08/14/85	68.67	529.78	1.7872	(178.2)	6.4320	0.0062	37.5018	0.05592	0.17905	0.6015	0.0015	0.0037	7,012,152	A 2	289	-5.1
187	08/14/85	68.69	528.27	1.7816	(177.7)	6.4121	0.0062	37.3857	0.05583	0.17851	0.6015	0.0015	0.0037	6,991,887	A 2	288	-5.0
188	08/14/85	68.69	527.03	1.7771	(177.2)	6.3967	0.0063	37.2969	0.05575	0.17810	0.6016	0.0015	0.0037	6,976,582	A 2	287	-5.0
189	08/14/85	68.70	525.73	1.7725	(176.8)	6.3812	0.0064	37.2000	0.05569	0.17766	0.6015	0.0015	0.0037	6,960,279	A 2	287	-5.0
190	08/14/85	67.62	513.85	1.7339	(215.3)	7.7694	0.0069	40.6230	0.05581	0.19245	0.6016	0.0015	0.0037	7,625,481	A 3	281	-5.9
191	08/14/85	67.64	512.86	1.7302	(214.9)	7.7546	0.0067	40.5408	0.05591	0.19208	0.6015	0.0015	0.0037	7,611,004	A 3	280	-5.9
192	08/14/85	67.63	511.77	1.7263	(214.4)	7.7390	0.0066	40.4530	0.05570	0.19167	0.6015	0.0015	0.0037	7,595,819	A 3	279	-5.9
193	08/14/85	67.67	511.18	1.7240	(214.2)	7.7306	0.0065	40.4040	0.05565	0.19147	0.6015	0.0015	0.0037	7,586,939	A 3	279	-5.8

Table 30F. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-4B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 5.7488 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.57015

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
58	08/05/85	78.84	630.48	2.1076	(11.3)	0.4085	0.0020	10.2435	0.02580	0.04814	0.6015	0.0024	0.0035	1,859,501	A 1	343	3.5
59	08/05/85	78.73	631.14	2.1106	(11.3)	0.4084	0.0020	10.2563	0.02582	0.04819	0.6019	0.0024	0.0035	1,861,904	A 1	343	3.4
60	08/05/85	78.63	631.87	2.1138	(11.3)	0.4089	0.0020	10.2702	0.02584	0.04823	0.6018	0.0024	0.0035	1,864,446	A 1	344	3.3
61	08/05/85	78.52	632.58	2.1170	(11.3)	0.4092	0.0020	10.2839	0.02586	0.04828	0.6020	0.0024	0.0035	1,866,983	A 1	344	3.2
66	08/05/85	73.70	604.46	2.0375	(50.9)	1.8352	0.0092	21.3833	0.03778	0.09904	0.6023	0.0021	0.0035	3,925,841	A 2	329	-1.2
67	08/05/85	73.78	601.62	2.0267	(50.6)	1.8262	0.0091	21.2762	0.03761	0.09858	0.6023	0.0021	0.0035	3,907,465	A 2	327	-1.1
68	08/05/85	73.80	599.08	2.0173	(50.4)	1.8187	0.0091	21.1812	0.03751	0.09815	0.6023	0.0021	0.0035	3,891,477	A 2	326	-1.1
69	08/05/85	73.92	596.55	2.0074	(50.2)	1.8116	0.0092	21.0843	0.03738	0.09775	0.6022	0.0022	0.0035	3,874,603	A 2	325	-1.0
70	08/05/85	70.86	579.95	1.9609	(88.2)	3.1843	0.0092	27.6651	0.04347	0.12339	0.6027	0.0017	0.0034	5,119,382	A 3	316	-3.5
71	08/05/85	70.87	578.06	1.9539	(87.9)	3.1735	0.0092	27.5707	0.04339	0.12299	0.6028	0.0017	0.0034	5,103,315	A 3	315	-3.5
72	08/05/85	70.90	576.12	1.9467	(87.6)	3.1626	0.0093	27.4723	0.04332	0.12257	0.6028	0.0017	0.0034	5,086,472	A 3	314	-3.5
73	08/05/85	70.95	574.56	1.9407	(87.4)	3.1543	0.0093	27.3920	0.04323	0.12224	0.6028	0.0017	0.0034	5,072,454	A 3	313	-3.4
194	08/14/85	70.29	517.10	1.7346	(136.5)	4.9259	0.0060	32.2745	0.05163	0.15561	0.6007	0.0016	0.0037	6,034,045	A 2	282	-3.5
195	08/14/85	70.44	517.10	1.7340	(136.5)	4.9262	0.0058	32.2698	0.05162	0.15567	0.6007	0.0016	0.0037	6,031,983	A 2	282	-3.4
196	08/14/85	70.53	517.10	1.7335	(136.5)	4.9259	0.0060	32.2659	0.05161	0.15569	0.6007	0.0016	0.0037	6,030,457	A 2	282	-3.3
197	08/14/85	70.63	517.19	1.7334	(136.5)	4.9269	0.0059	32.2667	0.05161	0.15574	0.6007	0.0016	0.0037	6,029,707	A 2	282	-3.2
198	08/14/85	68.34	505.10	1.6990	(212.0)	7.6516	0.0066	39.8751	0.05531	0.18941	0.6011	0.0015	0.0037	7,488,873	A 3	276	-5.2
199	08/14/85	68.33	505.02	1.6987	(212.0)	7.6521	0.0064	39.8671	0.05532	0.18937	0.6010	0.0015	0.0037	7,487,572	A 3	276	-5.2
200	08/14/85	68.33	504.89	1.6983	(212.0)	7.6519	0.0062	39.8552	0.05531	0.18932	0.6009	0.0015	0.0037	7,485,510	A 3	276	-5.2
201	08/14/85	68.33	504.43	1.6966	(211.7)	7.6407	0.0067	39.8179	0.05558	0.18915	0.6011	0.0015	0.0037	7,478,959	A 3	275	-5.2

Table 30G. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-5B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 6.6239 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.65694

Run No.	Date	Orifice			Diff. Press.			Mass Flow Rate			Discharge Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	Throat	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
74	08/06/85	81.49	609.22	2.0181	(8.9)	0.3199	0.0010	12.3142	0.02546	0.05436	0.5999	0.0018	0.0034	2,239,247	A 2	331	6.3
75	08/06/85	81.55	608.97	2.0169	(8.9)	0.3195	0.0010	12.3079	0.02545	0.05435	0.6002	0.0019	0.0034	2,238,016	A 2	331	6.3
76	08/06/85	81.63	608.55	2.0150	(8.8)	0.3190	0.0010	12.2975	0.02544	0.05432	0.6004	0.0019	0.0034	2,236,050	A 2	331	6.4
77	08/06/85	81.65	607.98	2.0129	(8.8)	0.3187	0.0010	12.2854	0.02542	0.05427	0.6005	0.0019	0.0034	2,233,987	A 2	331	6.4
78	08/06/85	76.21	605.40	2.0312	(20.6)	0.7447	0.0012	18.8754	0.03584	0.08429	0.6008	0.0016	0.0034	3,457,676	A 2	329	1.3
79	08/06/85	76.11	602.84	2.0225	(20.6)	0.7417	0.0013	18.7943	0.03792	0.08391	0.6007	0.0017	0.0034	3,444,665	A 2	328	1.2
80	08/06/85	75.94	597.28	2.0031	(20.3)	0.7343	0.0013	18.6164	0.03652	0.08310	0.6009	0.0017	0.0034	3,415,736	A 2	325	1.1
81	08/06/85	75.92	592.93	1.9870	(20.2)	0.7292	0.0013	18.4734	0.03609	0.08247	0.6008	0.0017	0.0034	3,392,000	A 2	323	1.1
82	08/06/85	71.18	572.95	1.9374	(45.2)	1.6331	0.0053	27.3078	0.04303	0.12201	0.6009	0.0017	0.0034	5,061,168	A 3	312	-3.1
83	08/06/85	71.18	570.75	1.9293	(45.1)	1.6264	0.0054	27.1981	0.04366	0.12154	0.6009	0.0018	0.0034	5,042,557	A 3	311	-3.1
84	08/06/85	71.11	564.72	1.9076	(44.6)	1.6113	0.0053	26.8995	0.04288	0.12022	0.6005	0.0018	0.0034	4,992,353	A 3	307	-3.1
85	08/06/85	71.15	562.37	1.8988	(44.5)	1.6043	0.0053	26.7801	0.04270	0.11971	0.6005	0.0018	0.0034	4,971,764	A 3	306	-3.0
202	08/15/85	67.71	560.56	1.9022	(98.2)	3.5426	0.0050	39.7715	0.05549	0.18900	0.5993	0.0014	0.0036	7,409,806	A 2	305	-6.2
203	08/15/85	67.95	560.68	1.9015	(98.2)	3.5439	0.0050	39.7689	0.05548	0.18913	0.5993	0.0014	0.0036	7,406,753	A 2	305	-6.0
204	08/15/85	68.15	560.80	1.9010	(98.2)	3.5444	0.0050	39.7689	0.05547	0.18925	0.5993	0.0014	0.0036	7,404,630	A 2	305	-5.8
205	08/15/85	68.32	560.98	1.9008	(98.3)	3.5474	0.0050	39.7734	0.05546	0.18937	0.5992	0.0014	0.0036	7,403,599	A 2	306	-5.7
206	08/15/85	66.35	540.91	1.8362	(152.8)	5.5137	0.0055	48.8052	0.05907	0.22912	0.5996	0.0014	0.0036	9,136,530	A 3	295	-7.5
207	08/15/85	66.38	540.54	1.8347	(152.7)	5.5125	0.0056	48.7684	0.05905	0.22897	0.5995	0.0014	0.0036	9,129,790	A 3	295	-7.5
208	08/15/85	66.41	540.18	1.8332	(152.6)	5.5086	0.0056	48.7326	0.05903	0.22883	0.5995	0.0014	0.0036	9,123,145	A 3	295	-7.4
209	08/15/85	66.45	539.86	1.8319	(152.5)	5.5044	0.0057	48.7047	0.05900	0.22873	0.5996	0.0014	0.0036	9,117,970	A 3	295	-7.4
210	08/15/85	64.64	531.86	1.8103	(210.2)	7.5859	0.0065	56.8852	0.06263	0.26435	0.5997	0.0014	0.0036	10,686,193	A 4	291	-8.9
211	08/15/85	64.62	532.34	1.8122	(210.3)	7.5916	0.0064	56.9374	0.06264	0.26456	0.5997	0.0013	0.0036	10,695,509	A 4	291	-8.9
212	08/15/85	64.61	532.75	1.8138	(210.6)	7.6003	0.0062	56.9866	0.06266	0.26477	0.5996	0.0013	0.0036	10,704,317	A 4	291	-9.0
213	08/15/85	64.61	533.17	1.8153	(210.7)	7.6039	0.0064	57.0305	0.06268	0.26497	0.5997	0.0013	0.0036	10,711,849	A 4	291	-9.0

Table 30H. Orifice Discharge Coefficient Values for Orifice Plate FE-9/O-6A Mounted in Meter Tube FE-9ABC

Orifice Diameter = 7.4996 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.74379

Run	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ----			Pipe Rey.	Gas/		-- Throat --	
No.		Temp.	Press.	Density		Mean	Std. Dev.	Total	Rand.	Syst.	Coefficient			Number	Num.		Press.	Temp.
		(°F)	(Psia)	(lb/CF)	(in.)	(psi)	(psi)	(pounds/second)			Mean	Rand.	Syst.		Noz.		(Psia)	(°F)°
154	08/12/85	77.66	578.56	1.9290	(10.4)	0.3764	0.0011	17.9814	0.03547	0.08076	0.5951	0.0018	0.0034	3,296,255	A	2	315	2.7
155	08/12/85	78.34	577.50	1.9220	(10.4)	0.3757	0.0011	17.9310	0.03542	0.08073	0.5951	0.0018	0.0034	3,284,611	A	2	314	3.3
156	08/12/85	78.59	576.51	1.9173	(10.4)	0.3749	0.0011	17.8926	0.03536	0.08063	0.5952	0.0018	0.0034	3,276,988	A	2	314	3.6
157	08/12/85	78.74	575.52	1.9130	(10.4)	0.3744	0.0011	17.8577	0.03536	0.08051	0.5951	0.0018	0.0034	3,270,466	A	2	313	3.7
158	08/12/85	74.83	567.32	1.9019	(19.8)	0.7150	0.0013	24.6077	0.04356	0.11479	0.5951	0.0016	0.0035	4,535,572	A	2	309	0.1
159	08/12/85	74.87	567.17	1.9012	(19.8)	0.7141	0.0013	24.5991	0.04355	0.11476	0.5954	0.0016	0.0035	4,533,863	A	2	309	0.2
160	08/12/85	74.85	567.34	1.9018	(19.8)	0.7145	0.0013	24.6068	0.04365	0.11479	0.5953	0.0016	0.0035	4,535,257	A	2	309	0.2
161	08/12/85	74.88	569.08	1.9080	(19.8)	0.7161	0.0013	24.6838	0.04374	0.11515	0.5955	0.0016	0.0035	4,548,030	A	2	310	0.2
162	08/13/85	68.31	538.15	1.8257	(49.9)	1.8010	0.0050	38.1147	0.08310	0.18176	0.5927	0.0020	0.0036	7,120,487	A	2	293	-5.3
163	08/13/85	68.39	537.05	1.8213	(49.7)	1.7954	0.0049	38.0277	0.08306	0.18140	0.5930	0.0020	0.0036	7,104,625	A	2	292	-5.3
164	08/13/85	68.53	536.06	1.8171	(49.7)	1.7940	0.0049	37.9492	0.08302	0.18111	0.5927	0.0020	0.0036	7,089,732	A	2	292	-5.1
165	08/13/85	68.57	535.06	1.8130	(49.6)	1.7907	0.0049	37.8703	0.08298	0.18076	0.5926	0.0020	0.0036	7,075,731	A	2	291	-5.1
170	08/13/85	64.55	489.29	1.6612	(102.1)	3.6861	0.0057	52.0855	0.09066	0.24267	0.5932	0.0018	0.0036	9,855,007	A	4	267	-8.5
171	08/13/85	64.52	487.47	1.6547	(101.8)	3.6723	0.0055	51.8847	0.09055	0.24173	0.5932	0.0018	0.0036	9,820,018	A	4	266	-8.5
172	08/13/85	64.57	485.69	1.6479	(101.4)	3.6600	0.0056	51.6847	0.09044	0.24087	0.5931	0.0018	0.0036	9,784,140	A	4	265	-8.5
173	08/13/85	64.60	484.30	1.6428	(101.1)	3.6501	0.0055	51.5237	0.09025	0.24015	0.5930	0.0018	0.0036	9,755,394	A	4	264	-8.4
222	08/19/85	60.17	646.29	2.1746	(133.7)	4.8246	0.0075	68.1341	0.10004	0.31431	0.5928	0.0014	0.0034	12,759,564	G	2	351	-14.6
223	08/19/85	60.00	645.91	2.1743	(133.5)	4.8197	0.0074	68.1051	0.10001	0.64337	0.5929	0.0014	0.0063	12,757,638	G	2	351	-14.8
224	08/19/85	60.00	645.53	2.1729	(133.5)	4.8195	0.0074	68.0680	0.09999	0.31383	0.5928	0.0014	0.0034	12,751,545	G	2	351	-14.8
225	08/19/85	60.71	645.35	2.1681	(133.4)	4.8163	0.0072	67.9793	0.09987	0.31413	0.5929	0.0014	0.0034	12,723,617	G	2	351	-14.2
226	08/19/85	60.50	614.49	2.0562	(201.9)	7.2876	0.0079	81.4410	0.10168	0.38169	0.5926	0.0013	0.0035	15,325,705	G	2	335	-14.1
227	08/19/85	60.70	614.65	2.0558	(202.0)	7.2910	0.0080	81.4401	0.10166	0.38192	0.5925	0.0013	0.0035	15,321,207	G	2	335	-13.9
228	08/19/85	60.85	614.69	2.0551	(202.0)	7.2912	0.0083	81.4198	0.10163	0.38201	0.5924	0.0013	0.0035	15,314,226	G	2	335	-13.7
229	08/19/85	60.95	614.65	2.0544	(202.1)	7.2922	0.0082	81.4110	0.10163	0.38209	0.5924	0.0013	0.0035	15,310,644	G	2	335	-13.7

Table 301. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-6B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 7.4997 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.74380

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
102	08/08/85	76.65	576.02	1.9169	(10.4)	0.3769	0.0013	17.8896	0.03475	0.08007	0.5936	0.0018	0.0034	3,287,149	A 2	313	1.7
103	08/08/85	76.78	575.08	1.9128	(10.4)	0.3764	0.0012	17.8552	0.03473	0.07996	0.5934	0.0018	0.0034	3,280,754	A 2	313	1.8
104	08/08/85	76.83	574.50	1.9105	(10.4)	0.3758	0.0012	17.8352	0.03470	0.07989	0.5936	0.0018	0.0034	3,277,148	A 2	313	1.9
105	08/08/85	76.87	573.87	1.9080	(10.4)	0.3753	0.0012	17.8134	0.03469	0.07980	0.5936	0.0018	0.0034	3,273,270	A 2	312	1.9
110	08/08/85	73.08	557.43	1.8662	(19.6)	0.7058	0.0014	24.1651	0.04123	0.11210	0.5938	0.0016	0.0035	4,473,457	A 2	303	-1.5
111	08/08/85	73.36	556.75	1.8625	(19.5)	0.7041	0.0014	24.1254	0.04118	0.11202	0.5941	0.0016	0.0035	4,464,910	A 2	303	-1.3
112	08/08/85	73.41	556.00	1.8595	(19.5)	0.7035	0.0014	24.0897	0.04116	0.11189	0.5940	0.0016	0.0035	4,458,503	A 2	303	-1.2
113	08/08/85	73.45	555.47	1.8574	(19.5)	0.7027	0.0015	24.0649	0.04113	0.11179	0.5940	0.0016	0.0035	4,454,005	A 2	302	-1.2
174	08/13/85	68.27	504.72	1.7016	(46.8)	1.6905	0.0049	35.6275	0.08198	0.17015	0.5923	0.0021	0.0036	6,688,967	A 2	275	-5.2
175	08/13/85	68.29	506.06	1.7064	(47.0)	1.6969	0.0049	35.7248	0.08204	0.17061	0.5920	0.0021	0.0036	6,705,638	A 2	275	-5.2
176	08/13/85	68.35	507.03	1.7097	(47.1)	1.6994	0.0049	35.7925	0.08200	0.17096	0.5921	0.0021	0.0036	6,716,809	A 2	276	-5.1
177	08/13/85	68.33	507.56	1.7117	(47.1)	1.7012	0.0049	35.8321	0.08200	0.17113	0.5921	0.0021	0.0036	6,723,899	A 2	276	-5.1
178	08/13/85	64.71	484.16	1.6410	(101.4)	3.6612	0.0056	51.5064	0.09016	0.24014	0.5922	0.0018	0.0036	9,748,634	A 4	264	-8.4
179	08/13/85	64.76	484.82	1.6432	(101.5)	3.6641	0.0055	51.5758	0.09021	0.24049	0.5924	0.0018	0.0036	9,760,087	A 4	264	-8.3
180	08/13/85	64.79	485.65	1.6462	(101.7)	3.6712	0.0053	51.6678	0.09023	0.24093	0.5923	0.0018	0.0036	9,775,945	A 4	265	-8.3
181	08/13/85	64.78	486.38	1.6489	(101.9)	3.6771	0.0056	51.7489	0.09026	0.24129	0.5923	0.0018	0.0036	9,790,304	A 4	265	-8.3
214	08/19/85	61.53	482.13	1.6458	(158.0)	5.7027	0.0077	64.3321	0.09074	0.54887	0.5915	0.0016	0.0059	12,222,443	A 2	263	-11.5
215	08/19/85	61.64	480.89	1.6396	(157.5)	5.6833	0.0074	64.1280	0.09063	0.30430	0.5917	0.0016	0.0036	12,179,013	A 2	262	-11.4
216	08/19/85	61.69	476.21	1.6222	(156.0)	5.6302	0.0076	63.4678	0.09006	0.30129	0.5915	0.0016	0.0036	12,061,363	A 2	260	-11.3
218	08/19/85	60.65	645.74	2.1688	(212.8)	7.6811	0.0084	85.8504	0.14813	0.40120	0.5924	0.0015	0.0034	16,069,690	G 2	352	-14.9
219	08/19/85	60.61	640.86	2.1511	(211.1)	7.6203	0.0088	85.0985	0.10594	0.39847	0.5920	0.0013	0.0034	15,942,611	G 2	349	-14.2
220	08/19/85	60.67	637.91	2.1398	(210.2)	7.5850	0.0089	84.6646	0.10538	0.39656	0.5919	0.0013	0.0034	15,867,823	G 2	347	-14.1
221	08/19/85	60.68	633.59	2.1239	(208.6)	7.5275	0.0091	84.0490	0.10578	0.39377	0.5920	0.0013	0.0034	15,763,598	G 2	345	-14.1

Table 30J. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-7B Mounted in Meter Tube FE-9ABC

Orifice Diameter = 0.9995 Inches-- Tube Diameter = 10.0829 Inches, Beta Ratio = 0.09913

Run No.	Date	------- Orifice Temp. (°F)	Press. (Psia)	------- Density (lb/CF)	----- Diff. Press. (in.)	Mean (psi)	----- Std. Dev. (psi)	---- Mass Flow Rate Total	Rand. (pounds/second)	---- Syst.	---- Discharge Coefficient Mean	Rand.	---- Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat Press. (Psia)	-- Temp. (°F)°
283	08/27/85	96.78	595.23	1.8927	(199.2)	7.1903	0.0088	1.15623	0.00208	0.00374	0.5957	0.0016	0.0029	206,483	A 1	323	21.1
284	08/27/85	97.83	594.70	1.8863	(199.0)	7.1821	0.0072	1.15352	0.00208	0.00375	0.5957	0.0015	0.0029	205,739	A 1	323	22.1
285	08/27/85	98.58	594.36	1.8819	(198.6)	7.1666	0.0145	1.15186	0.00207	0.00375	0.5961	0.0016	0.0029	205,259	A 1	323	22.8
286	08/27/85	99.19	594.08	1.8783	(198.7)	7.1730	0.0069	1.15074	0.00207	0.00376	0.5959	0.0015	0.0029	204,909	A 1	323	23.2
310	08/29/85	96.62	599.69	1.9057	(12.7)	0.4595	0.0024	0.29430	0.00058	0.00097	0.5991	0.0022	0.0029	52,627	A 1	326	20.6
311	08/29/85	96.72	598.79	1.9022	(12.7)	0.4585	0.0027	0.29382	0.00057	0.00097	0.5994	0.0023	0.0029	52,541	A 1	326	20.7
312	08/29/85	96.72	597.91	1.8991	(12.7)	0.4577	0.0025	0.29338	0.00057	0.00097	0.5995	0.0022	0.0029	52,471	A 1	325	20.7
313	08/29/85	96.58	597.03	1.8968	(12.7)	0.4572	0.0026	0.29296	0.00057	0.00097	0.5993	0.0023	0.0029	52,411	A 1	325	20.6
314	08/29/85	97.14	597.76	1.8951	(20.0)	0.7230	0.0026	0.36798	0.00059	0.00121	0.5989	0.0018	0.0029	65,787	A 2	325	20.7
315	08/29/85	97.18	598.13	1.8962	(20.0)	0.7224	0.0028	0.36819	0.00059	0.00121	0.5993	0.0018	0.0029	65,819	A 2	325	20.8
316	08/29/85	97.11	598.50	1.8978	(20.0)	0.7223	0.0027	0.36847	0.00059	0.00121	0.5995	0.0018	0.0029	65,870	A 2	326	20.7
317	08/29/85	97.11	598.68	1.8974	(20.0)	0.7219	0.0027	0.36851	0.00059	0.00121	0.5998	0.0018	0.0029	65,877	A 2	326	20.7
318	08/29/85	97.01	597.98	1.8939	(51.7)	1.8653	0.0089	0.58997	0.00085	0.00193	0.5977	0.0020	0.0029	105,509	A 2	325	20.7
319	08/29/85	97.08	598.16	1.8943	(51.7)	1.8658	0.0089	0.59018	0.00085	0.00193	0.5978	0.0020	0.0029	105,535	A 2	325	20.7
320	08/29/85	97.00	598.34	1.8952	(51.7)	1.8651	0.0091	0.59039	0.00085	0.00193	0.5980	0.0020	0.0029	105,581	A 2	325	20.6
321	08/29/85	96.99	598.57	1.8960	(51.7)	1.8657	0.0090	0.59065	0.00085	0.00193	0.5980	0.0020	0.0029	105,625	A 2	326	20.6
322	08/29/85	96.72	587.58	1.8618	(94.5)	3.4089	0.0109	0.79385	0.00101	0.00260	0.5997	0.0016	0.0029	142,169	A 2	320	21.0
323	08/29/85	96.68	586.85	1.8595	(94.4)	3.4083	0.0090	0.79281	0.00101	0.00260	0.5994	0.0015	0.0029	142,004	A 2	319	21.0
324	08/29/85	96.69	586.24	1.8574	(94.3)	3.4033	0.0092	0.79188	0.00101	0.00260	0.5994	0.0015	0.0029	141,848	A 2	319	21.0
325	08/29/85	96.67	585.73	1.8557	(94.2)	3.3991	0.0092	0.79119	0.00101	0.00259	0.5996	0.0015	0.0029	141,736	A 2	319	21.0
326	08/30/85	97.60	597.03	1.8901	(151.2)	5.4559	0.0080	1.00965	0.00094	0.00331	0.5979	0.0013	0.0029	180,376	A 4	325	21.7
327	08/30/85	97.82	596.10	1.8860	(150.9)	5.4457	0.0085	1.00776	0.00093	0.00331	0.5980	0.0013	0.0029	180,011	A 4	324	21.9
328	08/30/85	97.95	595.29	1.8827	(150.6)	5.4367	0.0081	1.00622	0.00093	0.00330	0.5981	0.0013	0.0029	179,728	A 4	324	22.0
329	08/30/85	98.20	594.52	1.8790	(150.4)	5.4286	0.0088	1.00459	0.00093	0.00330	0.5982	0.0013	0.0029	179,398	A 4	323	22.1

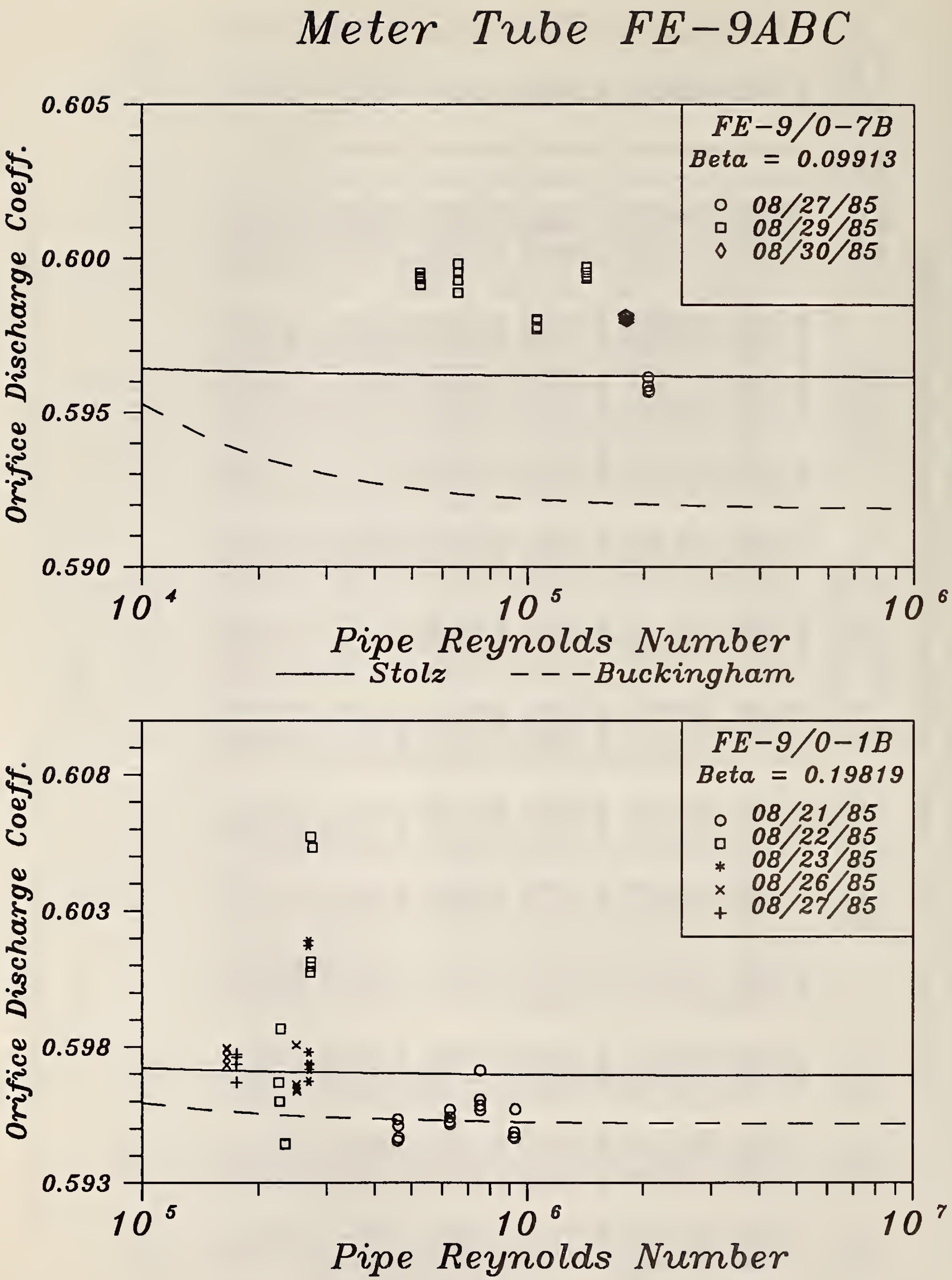


Figure 12A. Discharge coefficient/Reynolds number plots, FE-9ABC, 10-inch meter tube, 10 orifice plates.

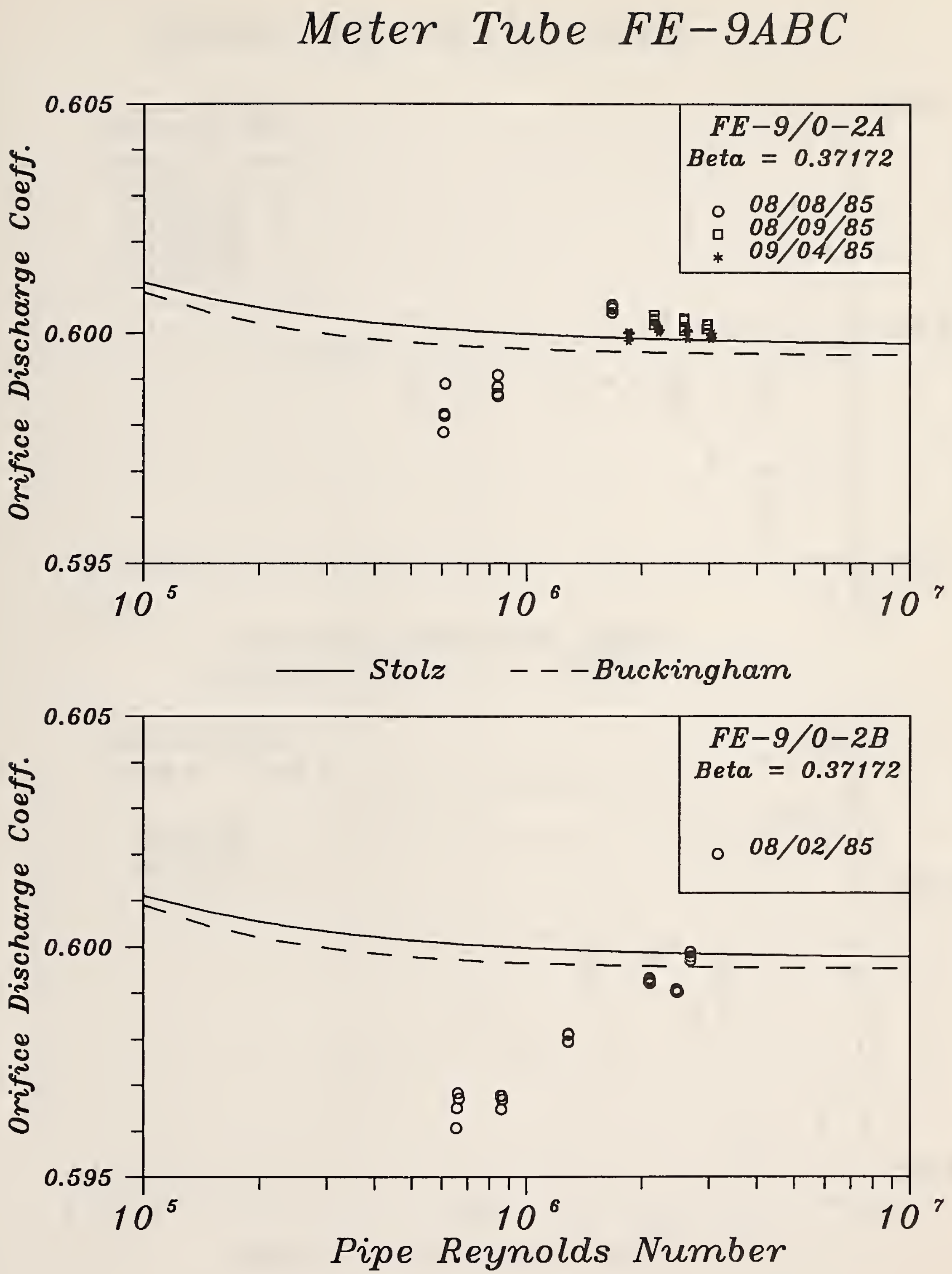


Figure 12B. Discharge coefficient/Reynolds number plots, FE-9ABC, 10-inch meter tube, 10 orifice plates.

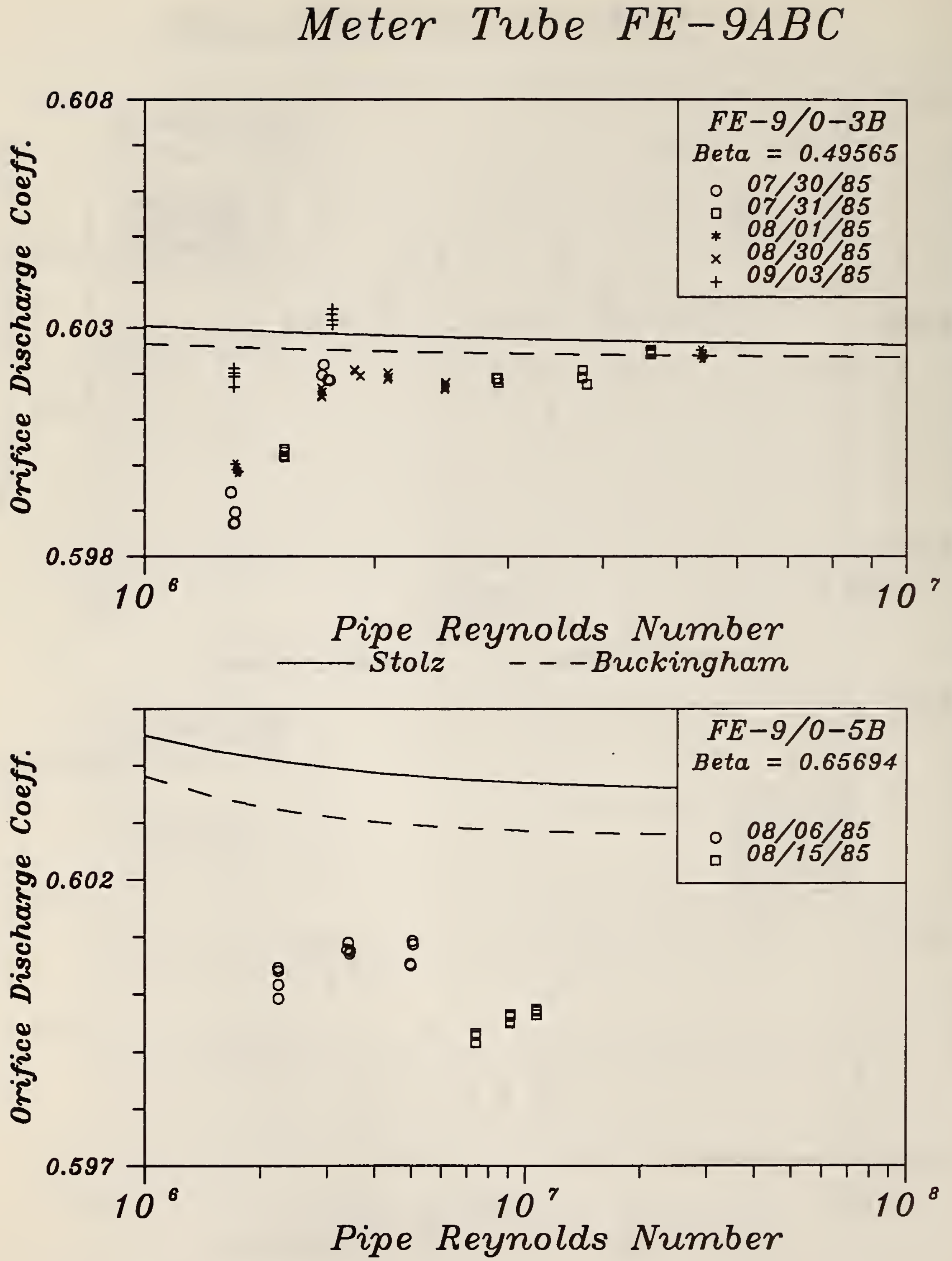


Figure 12C. Discharge coefficient/Reynolds number plots, FE-9ABC, 10-inch meter tube, 10 orifice plates.

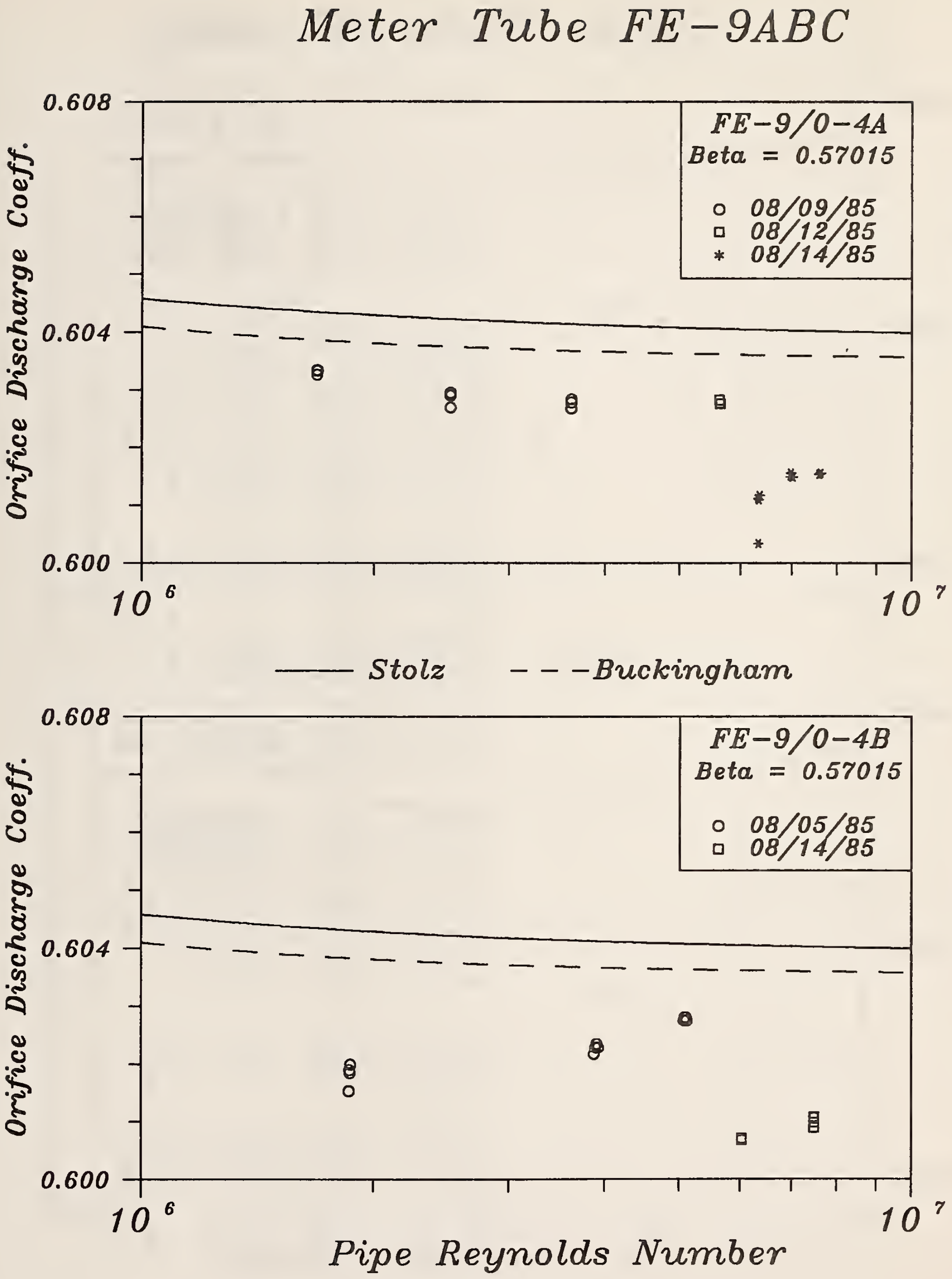


Figure 12D. Discharge coefficient/Reynolds number plots, FE-9ABC, 10-inch meter tube, 10 orifice plates.

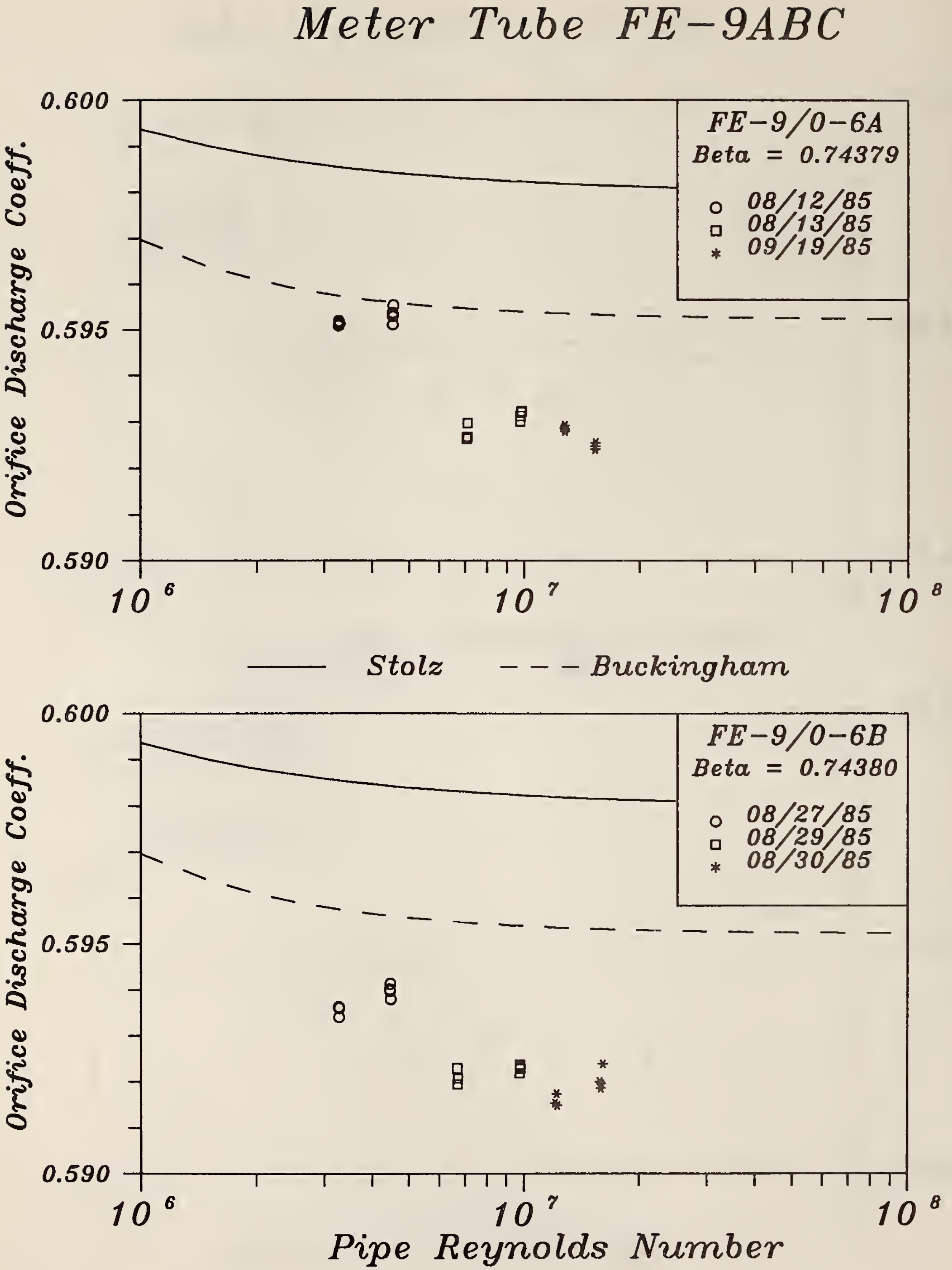


Figure 12E. Discharge coefficient/Reynolds number plots, FE-9ABC, 10-inch meter tube, 10 orifice plates.

Table 31A. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-1A Mounted in Meter Tube FE-0ABC

Orifice Diameter = 1.9987 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.19947

Run No.	Date	Orifice			Diff. Press.			Mass Flow Rate			Discharge Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	Throat	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
915	11/07/84	66.81	605.31	1.9514	(20.1)	0.7242	0.0055	1.48932	0.00494	0.00413	0.5967	0.0033	0.0024	281,151	G 2	328	-8.5
916	11/07/84	67.01	604.02	1.9467	(20.1)	0.7259	0.0057	1.48577	0.00494	0.00412	0.5953	0.0034	0.0024	280,453	G 2	327	-8.3
917	11/07/84	67.03	602.50	1.9413	(20.0)	0.7231	0.0052	1.48170	0.00494	0.00411	0.5956	0.0032	0.0024	279,746	G 2	326	-8.2
918	11/07/84	67.03	598.65	1.9278	(19.9)	0.7165	0.0055	1.47180	0.00495	0.00409	0.5964	0.0034	0.0025	278,041	G 2	324	-8.2
919	11/07/84	68.28	570.38	1.8279	(50.1)	1.8064	0.0121	2.27681	0.01142	0.00659	0.5965	0.0039	0.0026	431,247	G 1	310	-6.5
920	11/07/84	68.32	569.29	1.8239	(50.0)	1.8052	0.0114	2.27208	0.01142	0.00658	0.5961	0.0038	0.0026	430,399	G 1	309	-6.5
921	11/07/84	68.46	567.64	1.8175	(49.9)	1.8009	0.0117	2.26479	0.01142	0.00656	0.5960	0.0039	0.0026	429,044	G 1	308	-6.3
922	11/07/84	68.54	566.44	1.8130	(49.9)	1.8018	0.0114	2.25964	0.01142	0.00655	0.5952	0.0039	0.0026	428,103	G 1	308	-6.3
955	11/15/84	73.33	615.08	1.9536	(8.7)	0.3134	0.0028	0.97118	0.00090	0.00278	0.5911	0.0029	0.0025	181,560	G 3	334	-3.8
956	11/15/84	73.78	615.35	1.9523	(8.7)	0.3126	0.0028	0.97081	0.00090	0.00279	0.5919	0.0029	0.0025	181,377	G 3	334	-3.3
957	11/15/84	74.21	615.69	1.9513	(8.7)	0.3130	0.0032	0.97067	0.00090	0.00280	0.5915	0.0032	0.0025	181,241	G 3	334	-2.7
958	11/15/84	74.66	616.16	1.9507	(8.7)	0.3148	0.0028	0.97083	0.00090	0.00280	0.5900	0.0029	0.0025	181,153	G 3	334	-2.3

Table 31B. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-1B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 1.9983 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.19943

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total	Rand.	Syst. (pounds/second)	---- Discharge ---- Coefficient Mean	Rand.	Syst.	Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
959	11/15/84	73.73	615.49	1.9507	(8.7)	0.3154	0.0029	0.96875	0.00090	0.00280	0.5885	0.0029	0.0025	181,022	G 3	334	-2.0
960	11/15/84	74.41	614.56	1.9446	(8.7)	0.3143	0.0028	0.96668	0.00090	0.00280	0.5891	0.0029	0.0025	180,504	G 3	333	-1.6
961	11/15/84	74.75	614.07	1.9413	(8.7)	0.3128	0.0036	0.96552	0.00090	0.00280	0.5903	0.0036	0.0025	180,222	G 3	333	-1.4
962	11/15/84	75.04	613.37	1.9375	(8.7)	0.3125	0.0032	0.96408	0.00090	0.00280	0.5903	0.0032	0.0025	179,903	G 3	333	-1.2

Table 31C. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-2A Mounted in Meter Tube FE-0ABC

Orifice Diameter = 3.7480 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.37405

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total	Rand. (pounds/second)	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
795	10/18/84	89.24	605.97	1.8525	(16.8)	0.6076	0.0018	4.72666	0.00613	0.02269	0.5978	0.0015	0.0036	866,248	G 1	329	12.3
796	10/18/84	89.25	605.02	1.8493	(16.8)	0.6062	0.0018	4.71932	0.00616	0.02265	0.5981	0.0016	0.0036	864,812	G 1	328	12.3
797	10/18/84	89.30	604.53	1.8475	(16.8)	0.6051	0.0018	4.71492	0.00612	0.02264	0.5983	0.0015	0.0036	864,014	G 1	328	12.4
798	10/18/84	89.30	604.07	1.8460	(16.8)	0.6049	0.0018	4.71120	0.00612	0.02262	0.5982	0.0015	0.0036	863,390	G 1	328	12.4
799	10/18/84	88.37	601.89	1.8441	(37.5)	1.3520	0.0014	7.04815	0.00645	0.02996	0.5988	0.0012	0.0033	1,293,465	G 2	327	11.4
800	10/18/84	87.78	601.94	1.8468	(37.5)	1.3523	0.0014	7.05323	0.00645	0.02993	0.5987	0.0012	0.0033	1,295,359	G 2	327	10.9
801	10/18/84	87.49	601.84	1.8478	(37.4)	1.3514	0.0015	7.05449	0.00645	0.02991	0.5989	0.0012	0.0033	1,296,086	G 2	327	10.7
802	10/18/84	87.12	601.78	1.8492	(37.4)	1.3508	0.0015	7.05684	0.00645	0.02988	0.5990	0.0012	0.0033	1,297,142	G 2	326	10.4
803	10/18/84	80.95	597.62	1.8629	(102.6)	3.7046	0.0062	11.7500	0.02129	0.05160	0.5996	0.0016	0.0034	2,178,365	G 2	324	4.7
804	10/18/84	81.24	601.31	1.8740	(103.3)	3.7266	0.0052	11.8219	0.01980	0.05195	0.5997	0.0015	0.0034	2,189,722	G 2	326	4.9
805	10/18/84	81.38	598.59	1.8643	(102.7)	3.7081	0.0055	11.7642	0.01971	0.05173	0.5998	0.0015	0.0034	2,179,502	G 2	325	5.1
806	10/18/84	81.58	598.70	1.8632	(102.8)	3.7099	0.0054	11.7620	0.01969	0.05175	0.5997	0.0015	0.0034	2,178,453	G 2	325	5.2
807	10/18/84	79.26	596.41	1.8659	(147.9)	5.3361	0.0054	14.1159	0.02051	0.06610	0.5994	0.0013	0.0036	2,622,938	G 2	324	3.2
808	10/18/84	79.34	596.33	1.8652	(147.8)	5.3345	0.0055	14.1133	0.02051	0.06610	0.5994	0.0013	0.0036	2,622,071	G 2	324	3.2
809	10/18/84	79.35	596.69	1.8664	(148.0)	5.3401	0.0053	14.1227	0.02052	0.06615	0.5993	0.0013	0.0036	2,623,638	G 2	324	3.2
810	10/18/84	79.46	596.97	1.8668	(148.0)	5.3417	0.0053	14.1283	0.02052	0.06620	0.5994	0.0013	0.0036	2,624,188	G 2	324	3.3

Table 31D. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-2B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 3.7480 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.37405

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Coefficient Mean	Coefficient Rand.	Coefficient Syst.			Press. (Psia)	Temp. (°F)°
811	10/19/84	89.92	681.67	2.0987	(19.0)	0.6853	0.0014	5.34350	0.00653	0.02562	0.5978	0.0013	0.0036	967,760	G 1	370	12.4
812	10/19/84	89.90	681.95	2.0997	(19.0)	0.6851	0.0014	5.34534	0.00653	0.02563	0.5980	0.0013	0.0036	968,069	G 1	370	12.4
813	10/19/84	89.67	682.08	2.1013	(19.0)	0.6851	0.0014	5.34784	0.00653	0.02563	0.5980	0.0013	0.0036	968,782	G 1	370	12.2
814	10/19/84	89.65	682.15	2.1030	(19.0)	0.6849	0.0014	5.35027	0.00653	0.02564	0.5981	0.0013	0.0036	969,101	G 1	370	12.2
815	10/19/84	87.44	680.11	2.1075	(42.5)	1.5330	0.0046	8.02088	0.00692	0.03386	0.5986	0.0014	0.0032	1,457,233	G 2	369	10.0
816	10/19/84	88.16	679.69	2.1024	(42.5)	1.5322	0.0046	8.00841	0.00691	0.03389	0.5985	0.0014	0.0032	1,453,781	G 2	369	10.6
817	10/19/84	88.80	679.21	2.0975	(42.4)	1.5302	0.0046	7.99556	0.00690	0.03391	0.5987	0.0014	0.0032	1,450,467	G 2	368	11.3
818	10/19/84	88.64	679.01	2.0976	(42.4)	1.5289	0.0047	7.99434	0.00690	0.03390	0.5988	0.0014	0.0032	1,450,572	G 2	368	11.2
819	10/19/84	80.04	673.43	2.1239	(115.9)	4.1835	0.0051	13.3328	0.02178	0.05817	0.5996	0.0014	0.0033	2,447,001	G 2	365	3.3
820	10/19/84	79.81	673.22	2.1244	(115.8)	4.1807	0.0053	13.3323	0.02178	0.05812	0.5997	0.0014	0.0033	2,447,692	G 2	365	3.1
821	10/19/84	79.75	673.09	2.1237	(115.9)	4.1812	0.0050	13.3293	0.02177	0.05809	0.5996	0.0014	0.0033	2,447,342	G 2	365	3.0
822	10/19/84	79.72	672.98	2.1234	(115.8)	4.1800	0.0052	13.3273	0.02177	0.05807	0.5997	0.0014	0.0033	2,446,964	G 2	365	3.0

Table 31E. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-3A Mounted in Meter Tube FE-OABC

Orifice Diameter = 4.9985 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.49885

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
735	10/15/84	84.77	686.11	2.1465	(12.9)	0.4663	0.0015	8.13219	0.00922	0.03401	0.5999	0.0015	0.0032	1,480,452	G 2	372	7.6
736	10/15/84	84.72	686.05	2.1466	(12.9)	0.4662	0.0015	8.13194	0.00922	0.03401	0.5999	0.0015	0.0032	1,480,521	G 2	372	7.6
737	10/15/84	84.63	685.95	2.1467	(12.9)	0.4661	0.0015	8.13179	0.00922	0.03400	0.6000	0.0015	0.0032	1,480,671	G 2	372	7.5
738	10/15/84	84.64	685.87	2.1464	(12.9)	0.4657	0.0015	8.13098	0.00922	0.03399	0.6002	0.0015	0.0032	1,480,539	G 2	372	7.5
739	10/15/84	82.36	684.36	2.1536	(22.7)	0.8187	0.0015	10.8217	0.02495	0.05115	0.6014	0.0017	0.0035	1,976,455	G 1	371	5.4
740	10/15/84	82.28	683.91	2.1528	(22.7)	0.8181	0.0015	10.8158	0.02494	0.05111	0.6015	0.0017	0.0035	1,975,659	G 1	371	5.4
741	10/15/84	82.22	683.56	2.1519	(22.7)	0.8175	0.0015	10.8110	0.02493	0.05108	0.6015	0.0017	0.0035	1,975,060	G 1	371	5.4
742	10/15/84	82.21	683.20	2.1507	(22.6)	0.8172	0.0016	10.8057	0.02492	0.05106	0.6015	0.0017	0.0035	1,974,190	G 1	371	5.4
743	10/15/84	76.35	677.78	2.1639	(50.6)	1.8272	0.0049	16.2224	0.02639	0.07504	0.6020	0.0015	0.0035	2,987,794	G 2	368	0.0
744	10/15/84	76.30	676.93	2.1613	(50.6)	1.8250	0.0049	16.2027	0.02638	0.07494	0.6019	0.0015	0.0035	2,984,746	G 2	367	-0.0
745	10/15/84	76.30	675.75	2.1571	(50.5)	1.8232	0.0049	16.1732	0.02634	0.07480	0.6017	0.0015	0.0035	2,979,846	G 2	367	-0.0
746	10/15/84	76.35	675.10	2.1548	(50.4)	1.8206	0.0049	16.1565	0.02632	0.07474	0.6018	0.0015	0.0035	2,976,990	G 2	366	0.0
747	10/15/84	71.29	666.15	2.1516	(103.8)	3.7463	0.0055	23.1485	0.03914	0.10589	0.6013	0.0014	0.0034	4,298,279	G 2	362	-4.6
748	10/15/84	71.22	665.52	2.1508	(103.7)	3.7439	0.0055	23.1319	0.03913	0.10580	0.6012	0.0014	0.0034	4,295,935	G 2	362	-4.6
749	10/15/84	71.18	665.09	2.1495	(103.6)	3.7401	0.0055	23.1174	0.03912	0.10572	0.6013	0.0014	0.0034	4,293,710	G 2	361	-4.6
750	10/15/84	71.20	664.67	2.1479	(103.6)	3.7396	0.0054	23.1010	0.03911	0.10565	0.6011	0.0014	0.0034	4,290,877	G 2	361	-4.6
751	10/15/84	69.03	659.22	2.1425	(155.3)	5.6057	0.0054	28.2859	0.04552	0.12870	0.6016	0.0013	0.0034	5,272,462	G 2	358	-6.5
752	10/15/84	69.10	659.23	2.1421	(155.4)	5.6079	0.0053	28.2827	0.04552	0.12871	0.6014	0.0013	0.0034	5,271,366	G 2	358	-6.5
753	10/15/84	69.03	659.10	2.1421	(155.4)	5.6073	0.0052	28.2796	0.04552	0.12867	0.6014	0.0013	0.0034	5,271,349	G 2	358	-6.6
754	10/15/84	69.06	658.80	2.1408	(155.3)	5.6042	0.0054	28.2647	0.04551	0.12861	0.6014	0.0013	0.0034	5,268,659	G 2	358	-6.5

Table 31F. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-3B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 4.9976 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.49876

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.		-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.				Press. (Psia)	Temp. (°F)°
712	10/12/84	83.61	648.84	2.0250	(12.2)	0.4398	0.0011	7.67893	0.00540	0.03203	0.6007	0.0013	0.0032	1,407,828	G	2	352	6.7
713	10/12/84	83.66	648.33	2.0230	(12.2)	0.4392	0.0011	7.67218	0.00539	0.03201	0.6009	0.0013	0.0032	1,406,612	G	2	352	6.8
714	10/12/84	83.70	647.94	2.0215	(12.2)	0.4390	0.0011	7.66811	0.00539	0.03200	0.6010	0.0013	0.0032	1,405,870	G	2	352	6.8
715	10/12/84	83.69	647.77	2.0210	(12.2)	0.4392	0.0011	7.66532	0.00538	0.03199	0.6007	0.0013	0.0032	1,405,424	G	2	351	6.8
716	10/12/84	81.43	646.43	2.0275	(21.4)	0.7707	0.0011	10.2062	0.02067	0.04816	0.6028	0.0016	0.0036	1,876,985	G	1	351	4.8
717	10/12/84	81.45	646.26	2.0268	(21.4)	0.7705	0.0011	10.2036	0.02067	0.04815	0.6028	0.0016	0.0036	1,876,507	G	1	351	4.8
718	10/12/84	81.45	645.96	2.0258	(21.3)	0.7699	0.0012	10.1986	0.02066	0.04813	0.6029	0.0016	0.0036	1,875,665	G	1	351	4.8
719	10/12/84	81.49	645.71	2.0247	(21.3)	0.7696	0.0011	10.1942	0.02066	0.04811	0.6029	0.0016	0.0036	1,874,830	G	1	351	4.9
720	10/12/84	77.30	642.16	2.0339	(47.9)	1.7275	0.0047	15.3074	0.02123	0.07110	0.6028	0.0015	0.0035	2,831,608	G	2	349	1.0
721	10/12/84	77.32	641.79	2.0325	(47.8)	1.7259	0.0047	15.2973	0.02122	0.07106	0.6028	0.0015	0.0035	2,829,822	G	2	349	1.1
722	10/12/84	77.27	641.81	2.0328	(47.9)	1.7271	0.0046	15.2986	0.02122	0.07106	0.6026	0.0015	0.0035	2,830,232	G	2	349	1.0
723	10/12/84	77.20	641.64	2.0324	(47.8)	1.7262	0.0047	15.2954	0.02122	0.07103	0.6027	0.0015	0.0035	2,829,980	G	2	348	1.0
727	10/12/84	72.48	635.76	2.0364	(98.8)	3.5661	0.0054	21.9973	0.02780	0.10112	0.6022	0.0013	0.0035	4,098,068	G	2	345	-3.3
728	10/12/84	72.50	635.67	2.0364	(98.8)	3.5646	0.0054	21.9956	0.02782	0.10112	0.6023	0.0013	0.0035	4,097,669	G	2	345	-3.3
729	10/12/84	72.56	635.54	2.0357	(98.7)	3.5635	0.0053	21.9887	0.02780	0.10110	0.6023	0.0013	0.0035	4,096,131	G	2	345	-3.2
730	10/12/84	72.70	635.61	2.0352	(98.8)	3.5647	0.0052	21.9863	0.02780	0.10114	0.6022	0.0013	0.0035	4,094,919	G	2	345	-3.1
731	10/12/84	70.10	632.48	2.0380	(148.6)	5.3632	0.0052	27.0205	0.03428	0.12347	0.6026	0.0013	0.0035	5,051,550	G	2	344	-5.5
732	10/12/84	70.08	632.27	2.0374	(148.5)	5.3592	0.0052	27.0204	0.03432	0.12346	0.6029	0.0013	0.0035	5,051,828	G	2	344	-5.5
733	10/12/84	70.04	631.20	2.0339	(148.3)	5.3518	0.0052	26.9650	0.03426	0.12320	0.6026	0.0013	0.0035	5,042,589	G	2	343	-5.5
734	10/12/84	70.04	630.83	2.0326	(148.2)	5.3489	0.0052	26.9567	0.03422	0.12316	0.6028	0.0013	0.0035	5,041,356	G	2	343	-5.5

Table 31G. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-4A Mounted in Meter Tube FE-0ABC

Orifice Diameter = 5.7488 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.57373

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
755	10/16/84	82.48	687.97	2.1722	(12.4)	0.4460	0.0011	10.8919	0.02779	0.05149	0.6020	0.0020	0.0035	1,987,334	G 1	373	5.5
756	10/16/84	83.10	688.09	2.1692	(12.4)	0.4461	0.0011	10.8861	0.02777	0.05157	0.6020	0.0020	0.0035	1,984,830	G 1	373	6.1
757	10/16/84	83.42	688.20	2.1679	(12.4)	0.4460	0.0011	10.8839	0.02776	0.05161	0.6021	0.0020	0.0035	1,983,629	G 1	373	6.4
758	10/16/84	83.50	688.32	2.1679	(12.4)	0.4461	0.0011	10.8853	0.02776	0.05163	0.6021	0.0020	0.0035	1,983,659	G 1	374	6.5
759	10/16/84	80.35	676.92	2.1334	(19.0)	0.6871	0.0012	13.3983	0.02801	0.05850	0.6020	0.0018	0.0033	2,456,758	G 2	367	3.5
760	10/16/84	80.30	676.58	2.1307	(19.0)	0.6862	0.0012	13.3865	0.02799	0.05844	0.6022	0.0018	0.0033	2,455,288	G 2	367	3.5
761	10/16/84	80.26	676.11	2.1293	(19.0)	0.6858	0.0012	13.3771	0.02798	0.05839	0.6022	0.0018	0.0033	2,453,838	G 2	367	3.4
762	10/16/84	80.22	675.71	2.1282	(19.0)	0.6857	0.0012	13.3694	0.02797	0.05835	0.6020	0.0018	0.0033	2,452,708	G 2	367	3.4
763	10/16/84	71.92	668.21	2.1476	(56.3)	2.0332	0.0047	23.1529	0.04075	0.10610	0.6026	0.0017	0.0034	4,296,748	G 2	363	-4.1
764	10/16/84	71.70	667.57	2.1466	(56.3)	2.0320	0.0047	23.1360	0.04074	0.10595	0.6025	0.0017	0.0034	4,295,244	G 2	362	-4.3
765	10/16/84	71.56	667.16	2.1460	(56.3)	2.0313	0.0048	23.1262	0.04074	0.10585	0.6024	0.0017	0.0034	4,294,476	G 2	362	-4.4
766	10/16/84	71.48	666.81	2.1361	(56.3)	2.0305	0.0047	23.0712	0.04066	0.10554	0.6025	0.0017	0.0034	4,287,231	G 2	362	-4.6
767	10/16/84	68.10	662.67	2.1390	(101.3)	3.6550	0.0051	30.9993	0.04805	0.13607	0.6027	0.0015	0.0033	5,789,377	G 3	360	-7.6
768	10/16/84	68.04	662.97	2.1401	(101.3)	3.6555	0.0053	31.0130	0.04805	0.13609	0.6028	0.0015	0.0033	5,792,250	G 3	360	-7.7
769	10/16/84	67.98	663.12	2.1410	(101.3)	3.6577	0.0052	31.0225	0.04806	0.20640	0.6026	0.0015	0.0047	5,794,334	G 3	360	-7.7
770	10/16/84	67.89	662.70	2.1401	(101.3)	3.6544	0.0050	31.0067	0.04808	0.13600	0.6027	0.0015	0.0033	5,792,458	G 3	360	-7.8
771	10/16/84	66.24	655.62	2.1269	(137.8)	4.9732	0.0052	36.0589	0.04942	0.15782	0.6025	0.0014	0.0033	6,757,298	G 4	356	-9.2
772	10/16/84	66.18	655.12	2.1255	(137.6)	4.9670	0.0053	36.0331	0.04940	0.15768	0.6026	0.0014	0.0033	6,753,503	G 4	356	-9.3
773	10/16/84	66.18	655.57	2.1271	(137.7)	4.9707	0.0053	36.0581	0.04941	0.15778	0.6026	0.0014	0.0033	6,757,736	G 4	356	-9.3
774	10/16/84	66.15	655.89	2.1284	(137.9)	4.9754	0.0052	36.0799	0.04947	0.15785	0.6025	0.0014	0.0033	6,761,752	G 4	356	-9.3

Table 31H. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-4B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 5.7488 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.57373

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand.	Syst.	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
775	10/17/84	81.71	689.36	2.1631	(12.4)	0.4463	0.0015	10.8836	0.02562	0.05129	0.6026	0.0020	0.0035	1,988,939	G 1	374	4.6
776	10/17/84	82.48	689.93	2.1609	(12.4)	0.4467	0.0015	10.8822	0.02560	0.05140	0.6025	0.0020	0.0035	1,986,648	G 1	374	5.3
777	10/17/84	83.09	691.25	2.1621	(12.4)	0.4475	0.0015	10.8952	0.02568	0.05157	0.6025	0.0020	0.0035	1,987,155	G 1	375	5.9
778	10/17/84	83.64	692.75	2.1642	(12.4)	0.4481	0.0015	10.9124	0.02564	0.05173	0.6028	0.0020	0.0035	1,988,517	G 1	376	6.4
779	10/17/84	81.13	696.52	2.1907	(19.6)	0.7058	0.0016	13.7681	0.02616	0.06021	0.6023	0.0016	0.0033	2,515,193	G 2	378	4.0
780	10/17/84	81.41	697.84	2.1936	(19.6)	0.7068	0.0015	13.7913	0.02619	0.06035	0.6025	0.0016	0.0033	2,518,103	G 2	378	4.3
781	10/17/84	81.53	699.00	2.1969	(19.6)	0.7082	0.0015	13.8134	0.02620	0.06048	0.6024	0.0016	0.0033	2,521,307	G 2	379	4.4
782	10/17/84	81.68	700.03	2.1996	(19.6)	0.7091	0.0015	13.8327	0.02624	0.06059	0.6025	0.0016	0.0033	2,523,975	G 2	380	4.5
783	10/17/84	73.15	697.04	2.2375	(58.9)	2.1255	0.0048	24.1360	0.03756	0.11089	0.6019	0.0015	0.0034	4,452,504	G 2	378	-3.2
784	10/17/84	72.94	697.21	2.2393	(58.9)	2.1272	0.0051	24.1489	0.03756	0.11086	0.6017	0.0015	0.0034	4,455,904	G 2	378	-3.4
785	10/17/84	72.82	696.97	2.2392	(58.9)	2.1267	0.0050	24.1442	0.03756	0.11080	0.6017	0.0015	0.0034	4,455,842	G 2	378	-3.5
786	10/17/84	72.69	696.63	2.2387	(58.9)	2.1240	0.0050	24.1353	0.03756	0.11072	0.6019	0.0015	0.0034	4,455,160	G 2	378	-3.6
787	10/17/84	68.98	689.31	2.2361	(105.5)	3.8074	0.0054	32.3187	0.04452	0.14214	0.6021	0.0013	0.0033	6,000,004	G 3	374	-7.0
788	10/17/84	68.88	689.26	2.2365	(105.5)	3.8080	0.0054	32.3180	0.04453	0.14209	0.6020	0.0013	0.0033	6,000,620	G 3	374	-7.0
789	10/17/84	68.83	689.89	2.2391	(105.5)	3.8092	0.0055	32.3522	0.04456	0.14221	0.6022	0.0013	0.0033	6,006,747	G 3	375	-7.1
790	10/17/84	68.80	690.16	2.2412	(105.6)	3.8124	0.0055	32.3734	0.04457	0.14229	0.6021	0.0013	0.0033	6,010,061	G 3	375	-7.1
791	10/17/84	66.65	674.55	2.1988	(141.9)	5.1215	0.0065	37.1769	0.04739	0.16282	0.6020	0.0013	0.0033	6,937,655	G 4	366	-9.0
792	10/17/84	66.54	669.15	2.1800	(140.8)	5.0807	0.0057	36.8659	0.04662	0.16144	0.6020	0.0013	0.0033	6,886,741	G 4	364	-9.0
793	10/17/84	66.43	663.72	2.1613	(139.7)	5.0406	0.0058	36.5571	0.04653	0.16007	0.6019	0.0013	0.0033	6,836,021	G 4	361	-9.1
794	10/17/84	66.33	658.24	2.1424	(138.5)	4.9984	0.0056	36.2439	0.04548	0.15868	0.6019	0.0013	0.0033	6,784,324	G 4	358	-9.1

Table 31I. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-5A Mounted in Meter Tube FE-0ABC

Orifice Diameter = 6.6241 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.66109

Run No.	Date	------- Orifice ------- Temp. (°F)			----- Diff. Press. ----- (in.)			---- Mass Flow Rate ---- Total			---- Discharge ---- Coefficient Mean			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat -- Press. (Psia)	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
827	10/22/84	82.05	654.84	2.0518	(9.5)	0.3434	0.0014	12.9100	0.02066	0.05675	0.6002	0.0018	0.0033	2,370,046	G 2	355	5.3
828	10/22/84	82.15	655.03	2.0519	(9.5)	0.3430	0.0014	12.9121	0.02067	0.05677	0.6007	0.0018	0.0033	2,370,061	G 2	355	5.3
829	10/22/84	82.23	654.91	2.0511	(9.5)	0.3430	0.0014	12.9085	0.02067	0.05677	0.6007	0.0018	0.0033	2,369,201	G 2	355	5.4
830	10/22/84	82.29	654.06	2.0479	(9.5)	0.3426	0.0013	12.8898	0.02065	0.05670	0.6006	0.0018	0.0033	2,365,898	G 2	355	5.5
831	10/22/84	74.79	649.98	2.0727	(22.2)	0.7999	0.0015	19.8037	0.02810	0.08763	0.6003	0.0014	0.0033	3,671,635	G 2	353	-1.3
832	10/22/84	74.58	648.85	2.0699	(22.1)	0.7981	0.0015	19.7720	0.02804	0.08743	0.6004	0.0014	0.0033	3,667,354	G 2	352	-1.5
833	10/22/84	74.47	648.29	2.0685	(22.1)	0.7979	0.0015	19.7568	0.02799	0.08734	0.6002	0.0014	0.0033	3,665,370	G 2	352	-1.6
834	10/22/84	74.41	647.74	2.0669	(22.1)	0.7974	0.0015	19.7402	0.02798	0.08724	0.6001	0.0014	0.0033	3,662,851	G 2	351	-1.6
835	10/22/84	68.93	638.71	2.0649	(50.4)	1.8206	0.0055	29.8474	0.03481	0.13158	0.6007	0.0015	0.0033	5,584,928	G 3	347	-6.6
836	10/22/84	68.96	640.53	2.0713	(50.6)	1.8268	0.0055	29.9370	0.03476	0.13197	0.6006	0.0014	0.0033	5,599,872	G 3	348	-6.6
837	10/22/84	68.89	641.35	2.0746	(50.6)	1.8261	0.0056	29.9824	0.03471	0.13214	0.6011	0.0015	0.0033	5,608,131	G 3	348	-6.6
838	10/22/84	68.84	641.93	2.0769	(50.7)	1.8288	0.0057	30.0092	0.03475	0.13223	0.6009	0.0015	0.0033	5,613,015	G 3	348	-6.7
899	10/30/84	60.23	597.42	1.9564	(139.1)	5.0210	0.0064	48.2417	0.13390	0.22193	0.6002	0.0021	0.0035	9,191,098	G 2	325	-14.3
900	10/30/84	60.30	594.30	1.9460	(138.3)	4.9914	0.0067	47.9803	0.13364	0.22081	0.6003	0.0022	0.0035	9,144,509	G 2	323	-14.2
901	10/30/84	60.38	592.66	1.9398	(137.9)	4.9775	0.0063	47.8379	0.13361	0.22023	0.6003	0.0022	0.0035	9,118,763	G 2	322	-14.1
902	10/30/84	60.47	591.29	1.9344	(137.6)	4.9654	0.0064	47.7152	0.13345	0.21974	0.6003	0.0022	0.0035	9,096,276	G 2	322	-14.0
903	10/30/84	62.10	595.28	1.9393	(104.0)	3.7550	0.0064	41.5227	0.12177	0.19297	0.6002	0.0023	0.0035	7,894,528	G 2	324	-12.6
904	10/30/84	62.16	594.55	1.9364	(103.9)	3.7491	0.0062	41.4657	0.12171	0.19276	0.6003	0.0023	0.0035	7,883,966	G 2	323	-12.5
905	10/30/84	62.29	594.52	1.9357	(104.0)	3.7526	0.0062	41.4564	0.12169	0.19279	0.6000	0.0023	0.0035	7,880,898	G 2	323	-12.4
906	10/30/84	62.35	594.69	1.9360	(104.0)	3.7526	0.0062	41.4678	0.12168	0.19288	0.6001	0.0023	0.0035	7,882,180	G 2	323	-12.3

Table 31J. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-5B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 6.6239 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.66107

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge Coefficient ----			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
839	10/23/84	82.13	631.74	1.9661	(9.2)	0.3310	0.0012	12.4147	0.02934	0.05462	0.6007	0.0020	0.0034	2,288,077	G 2	343	5.4
840	10/23/84	82.41	629.86	1.9585	(9.1)	0.3297	0.0012	12.3721	0.02925	0.05448	0.6009	0.0021	0.0034	2,280,057	G 2	342	5.6
841	10/23/84	82.63	628.55	1.9530	(9.1)	0.3291	0.0012	12.3414	0.02925	0.05439	0.6009	0.0021	0.0034	2,274,194	G 2	341	5.8
842	10/23/84	82.80	626.26	1.9446	(9.1)	0.3272	0.0012	12.2928	0.02921	0.05421	0.6015	0.0021	0.0034	2,265,514	G 2	340	6.0
843	10/23/84	75.24	612.64	1.9333	(20.9)	0.7528	0.0014	18.5721	0.03703	0.08241	0.6009	0.0017	0.0034	3,463,166	G 2	333	-0.7
844	10/23/84	75.16	609.99	1.9247	(20.8)	0.7497	0.0014	18.4916	0.03678	0.08204	0.6008	0.0016	0.0034	3,449,859	G 2	331	-0.8
845	10/23/84	75.12	609.17	1.9221	(20.7)	0.7487	0.0013	18.4665	0.03675	0.08192	0.6008	0.0016	0.0034	3,445,795	G 2	331	-0.8
846	10/23/84	75.06	608.55	1.9203	(20.7)	0.7477	0.0014	18.4487	0.03672	0.08183	0.6009	0.0016	0.0034	3,443,065	G 2	330	-0.8
847	10/23/84	69.30	598.83	1.9132	(47.2)	1.7041	0.0061	27.8232	0.04672	0.12299	0.6014	0.0018	0.0034	5,239,949	G 3	325	-6.0
848	10/23/84	69.23	598.51	1.9124	(47.2)	1.7034	0.0059	27.8123	0.04668	0.12291	0.6014	0.0018	0.0034	5,238,652	G 3	325	-6.1
849	10/23/84	69.14	598.44	1.9126	(47.2)	1.7026	0.0060	27.8123	0.04668	0.12288	0.6015	0.0018	0.0034	5,239,324	G 3	325	-6.2
850	10/23/84	69.09	598.01	1.9114	(47.1)	1.6992	0.0060	27.7929	0.04667	0.12277	0.6019	0.0018	0.0034	5,236,310	G 3	325	-6.2
891	10/30/84	62.36	658.09	2.1619	(90.5)	3.2654	0.0062	40.8087	0.12011	0.19014	0.5992	0.0022	0.0035	7,677,714	G 2	357	-12.8
892	10/30/84	62.52	657.62	2.1589	(90.4)	3.2635	0.0064	40.7656	0.12008	0.19003	0.5992	0.0022	0.0035	7,668,852	G 2	357	-12.6
893	10/30/84	62.59	656.89	2.1559	(90.3)	3.2594	0.0064	40.7143	0.12005	0.18983	0.5992	0.0022	0.0035	7,659,460	G 2	357	-12.6
894	10/30/84	62.61	656.03	2.1527	(90.2)	3.2562	0.0062	40.6568	0.12003	0.18959	0.5991	0.0022	0.0035	7,649,460	G 2	356	-12.5
895	10/30/84	60.47	635.10	2.0882	(148.3)	5.3512	0.0063	51.4119	0.13482	0.23627	0.5997	0.0020	0.0034	9,733,529	G 2	345	-14.4
896	10/30/84	60.45	633.59	2.0829	(148.0)	5.3400	0.0065	51.2833	0.13475	0.23567	0.5996	0.0020	0.0034	9,711,849	G 2	345	-14.4
897	10/30/84	60.46	632.26	2.0780	(147.7)	5.3300	0.0063	51.1633	0.13471	0.23514	0.5995	0.0020	0.0034	9,691,084	G 2	344	-14.4
898	10/30/84	60.49	630.66	2.0721	(147.3)	5.3154	0.0066	51.0315	0.13469	0.23457	0.5996	0.0020	0.0034	9,668,220	G 2	343	-14.3

Table 31K. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-6A Mounted in Meter Tube FE-0ABC

Orifice Diameter = 7.4996 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.74846

Run No.	Date	------- Orifice -------			----- Diff. Press. -----			---- Mass Flow Rate ----			---- Discharge ---- Coefficient			Pipe Rey. Number	Gas/ Num. Noz.	-- Throat --	
		Temp. (°F)	Press. (Psia)	Density (lb/CF)	(in.)	Mean (psi)	Std. Dev. (psi)	Total (pounds/second)	Rand. (pounds/second)	Syst. (pounds/second)	Mean	Rand.	Syst.			Press. (Psia)	Temp. (°F)°
851	10/24/84	76.66	505.93	1.5694	(9.1)	0.3280	0.0013	15.1789	0.02937	0.06802	0.5933	0.0021	0.0035	2,868,920	G 2	275	1.3
852	10/24/84	77.07	504.67	1.5650	(9.1)	0.3270	0.0013	15.1379	0.02926	0.06794	0.5935	0.0021	0.0035	2,860,111	G 2	274	1.7
853	10/24/84	77.44	503.74	1.5605	(9.0)	0.3259	0.0012	15.1030	0.02920	0.06787	0.5939	0.0021	0.0035	2,852,446	G 2	273	2.0
854	10/24/84	77.78	503.16	1.5574	(9.0)	0.3256	0.0013	15.0799	0.02916	0.06784	0.5939	0.0021	0.0035	2,846,973	G 2	273	2.4
855	10/24/84	73.09	497.92	1.5570	(17.3)	0.6246	0.0014	20.8875	0.03503	0.09698	0.5940	0.0018	0.0036	3,971,695	G 2	271	-1.8
856	10/24/84	73.03	497.98	1.5574	(17.3)	0.6245	0.0014	20.8906	0.03504	0.09698	0.5941	0.0018	0.0036	3,972,563	G 2	271	-1.8
857	10/24/84	73.00	498.28	1.5585	(17.3)	0.6251	0.0014	20.9052	0.03506	0.09703	0.5940	0.0018	0.0036	3,975,308	G 2	271	-1.9
858	10/24/84	72.96	498.10	1.5580	(17.3)	0.6255	0.0014	20.8998	0.03512	0.09700	0.5937	0.0018	0.0036	3,974,612	G 2	271	-1.9
879	10/29/84	58.64	574.44	1.8850	(120.4)	4.3438	0.0072	60.3329	0.07919	0.27376	0.5909	0.0015	0.0034	11,562,419	G 4	312	-15.5
880	10/29/84	58.82	576.41	1.8912	(120.8)	4.3589	0.0078	60.5380	0.07918	0.27483	0.5910	0.0015	0.0034	11,595,195	G 4	313	-15.3
881	10/29/84	59.02	579.03	1.8995	(121.2)	4.3747	0.0072	60.8116	0.07922	0.27621	0.5912	0.0015	0.0034	11,639,690	G 4	315	-15.2
882	10/29/84	59.09	580.40	1.9041	(121.5)	4.3835	0.0072	60.9572	0.07920	0.27691	0.5914	0.0015	0.0034	11,663,508	G 4	316	-15.1
883	10/29/84	60.81	599.59	1.9637	(89.6)	3.2328	0.0070	53.1829	0.07480	0.24403	0.5918	0.0015	0.0034	10,121,616	G 3	326	-13.7
884	10/29/84	60.85	600.63	1.9672	(89.8)	3.2399	0.0071	53.2768	0.07482	0.24448	0.5916	0.0015	0.0034	10,137,223	G 3	326	-13.7
885	10/29/84	60.88	601.61	1.9705	(89.9)	3.2430	0.0074	53.3670	0.07484	0.24490	0.5918	0.0015	0.0034	10,152,425	G 3	327	-13.7
886	10/29/84	60.92	602.24	1.9727	(90.0)	3.2492	0.0069	53.4243	0.07483	0.24519	0.5916	0.0015	0.0034	10,161,298	G 3	327	-13.6
887	10/29/84	63.19	620.62	2.0262	(57.5)	2.0734	0.0063	43.2741	0.07070	0.20160	0.5920	0.0017	0.0035	8,182,412	G 2	337	-11.7
888	10/29/84	63.24	621.85	2.0298	(57.5)	2.0765	0.0063	43.3537	0.07071	0.20198	0.5921	0.0017	0.0035	8,195,421	G 2	337	-11.7
889	10/29/84	63.26	622.64	2.0325	(57.6)	2.0788	0.0062	43.4099	0.07075	0.20225	0.5922	0.0017	0.0035	8,204,749	G 2	338	-11.7
890	10/29/84	63.31	623.56	2.0355	(57.7)	2.0838	0.0063	43.4749	0.07078	0.20258	0.5919	0.0017	0.0035	8,215,324	G 2	338	-11.7

Table 31L. Orifice Discharge Coefficient Values for Orifice Plate FE-9/0-6B Mounted in Meter Tube FE-0ABC

Orifice Diameter = 7.4997 Inches-- Tube Diameter = 10.0200 Inches, Beta Ratio = 0.74847

Run No.	Date	------- Orifice ------- Temp. (°F)	Press. (Psia)	Density (lb/CF)	----- Diff. Press. ----- (in.)	Mean (psi)	Std. Dev. (psi)	---- Mass Flow Rate ---- Total (pounds/second)	Rand.	Syst.	---- Discharge Coefficient ---- Mean	Rand.	Syst.	Pipe Rey. Number	Gas/	Num. Noz.	-- Throat -- Press. (Psia)	Temp. (°F)°
859	10/24/84	77.41	514.58	1.5960	(9.3)	0.3340	0.0012	15.4444	0.02954	0.06936	0.5932	0.0020	0.0035	2,912,694	G	2	279	2.0
860	10/24/84	77.73	515.36	1.5973	(9.3)	0.3344	0.0013	15.4626	0.03007	0.06951	0.5933	0.0021	0.0035	2,914,508	G	2	280	2.3
861	10/24/84	78.19	526.12	1.6312	(9.5)	0.3417	0.0013	15.7883	0.03171	0.07105	0.5930	0.0021	0.0035	2,969,615	G	2	286	2.6
862	10/24/84	78.27	530.35	1.6449	(9.5)	0.3442	0.0012	15.9181	0.02982	0.07163	0.5933	0.0020	0.0035	2,991,926	G	2	288	2.7
863	10/24/84	72.85	526.80	1.6542	(18.4)	0.6624	0.0014	22.1533	0.03618	0.10262	0.5935	0.0017	0.0036	4,196,334	G	2	286	-2.2
864	10/24/84	72.85	527.89	1.6578	(18.4)	0.6636	0.0014	22.2006	0.03626	0.10283	0.5936	0.0017	0.0036	4,204,640	G	2	287	-2.2
865	10/24/84	72.85	529.71	1.6640	(18.5)	0.6659	0.0015	22.2817	0.03614	0.10319	0.5936	0.0017	0.0036	4,218,899	G	2	288	-2.3
866	10/24/84	72.80	529.94	1.6649	(18.5)	0.6664	0.0014	22.2933	0.03609	0.10323	0.5935	0.0017	0.0036	4,221,221	G	2	288	-2.3
867	10/26/84	60.91	530.06	1.7151	(110.7)	3.9937	0.0065	55.2587	0.06469	0.25316	0.5917	0.0014	0.0035	10,639,606	G	4	288	-13.1
868	10/26/84	60.96	530.69	1.7171	(110.8)	3.9982	0.0067	55.3221	0.06476	0.25348	0.5917	0.0014	0.0035	10,650,187	G	4	289	-13.0
869	10/26/84	60.99	531.41	1.7194	(111.0)	4.0062	0.0067	55.3949	0.06478	0.25383	0.5915	0.0014	0.0035	10,662,518	G	4	289	-13.0
870	10/26/84	60.99	531.93	1.7213	(111.1)	4.0096	0.0068	55.4541	0.06478	0.34672	0.5916	0.0014	0.0045	10,673,106	G	4	289	-13.0
871	10/26/84	62.38	545.51	1.7625	(81.4)	2.9389	0.0064	48.0366	0.06243	0.22212	0.5917	0.0015	0.0035	9,208,307	G	3	297	-11.9
872	10/26/84	62.34	545.40	1.7626	(81.5)	2.9396	0.0065	48.0302	0.06244	0.22207	0.5915	0.0015	0.0035	9,207,686	G	3	296	-11.9
873	10/26/84	62.34	545.48	1.7628	(81.6)	2.9452	0.0066	48.0346	0.06244	0.22209	0.5910	0.0015	0.0035	9,208,430	G	3	297	-11.9
874	10/26/84	62.33	545.52	1.7630	(81.4)	2.9395	0.0061	48.0405	0.06244	0.22211	0.5916	0.0015	0.0035	9,209,645	G	3	297	-11.9
875	10/26/84	64.28	558.37	1.7987	(51.7)	1.8641	0.0057	38.6371	0.05312	0.18116	0.5916	0.0016	0.0035	7,373,097	G	2	303	-10.2
876	10/26/84	64.25	557.48	1.7958	(51.6)	1.8625	0.0059	38.5731	0.05320	0.18084	0.5914	0.0016	0.0035	7,362,153	G	2	303	-10.3
877	10/26/84	64.24	556.51	1.7925	(51.4)	1.8562	0.0058	38.5036	0.05310	0.18052	0.5919	0.0016	0.0036	7,349,969	G	2	302	-10.3
878	10/26/84	64.26	554.45	1.7852	(51.3)	1.8510	0.0057	38.3528	0.05301	0.17985	0.5916	0.0016	0.0036	7,323,293	G	2	301	-10.2

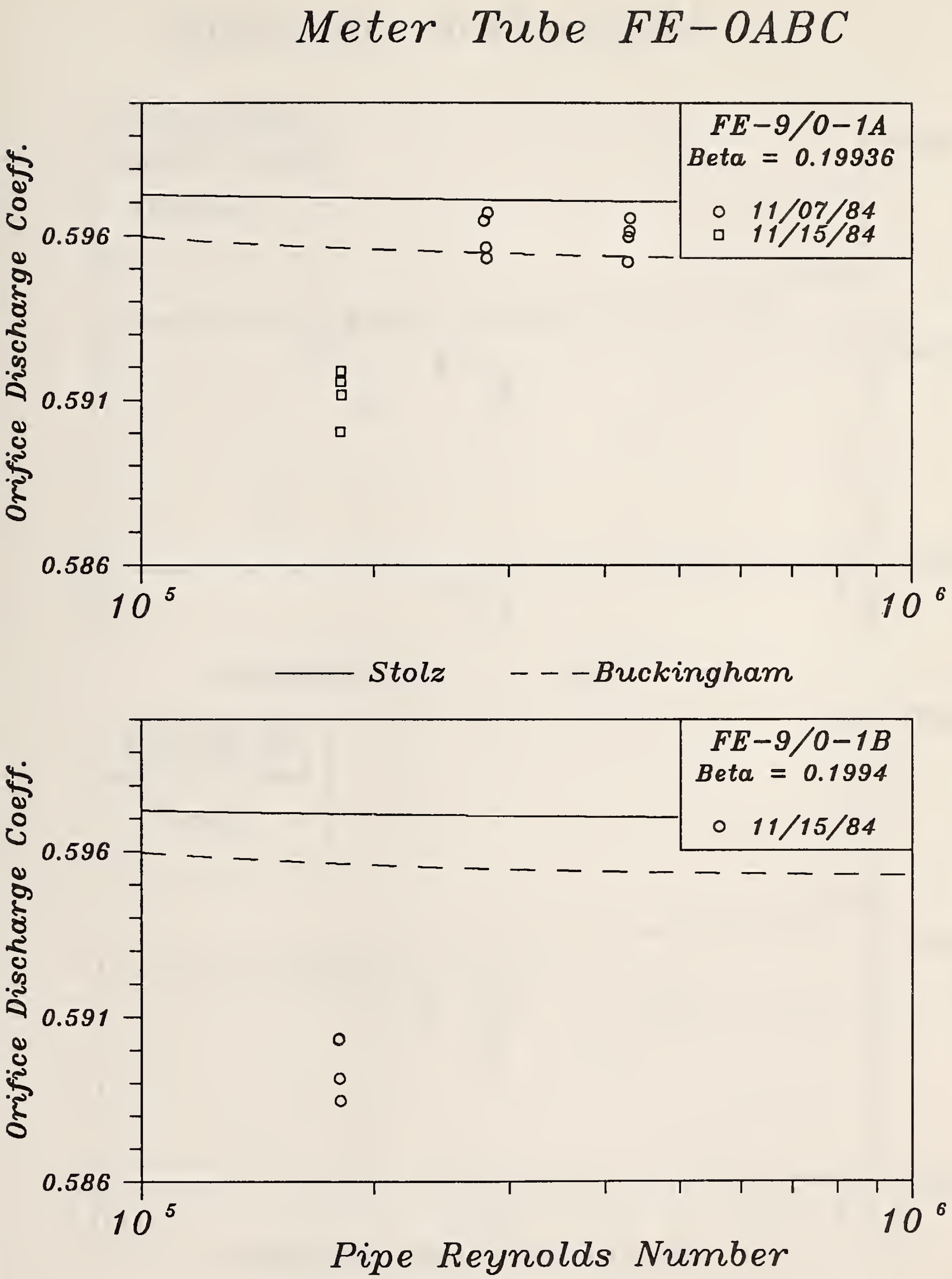


Figure 13A. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

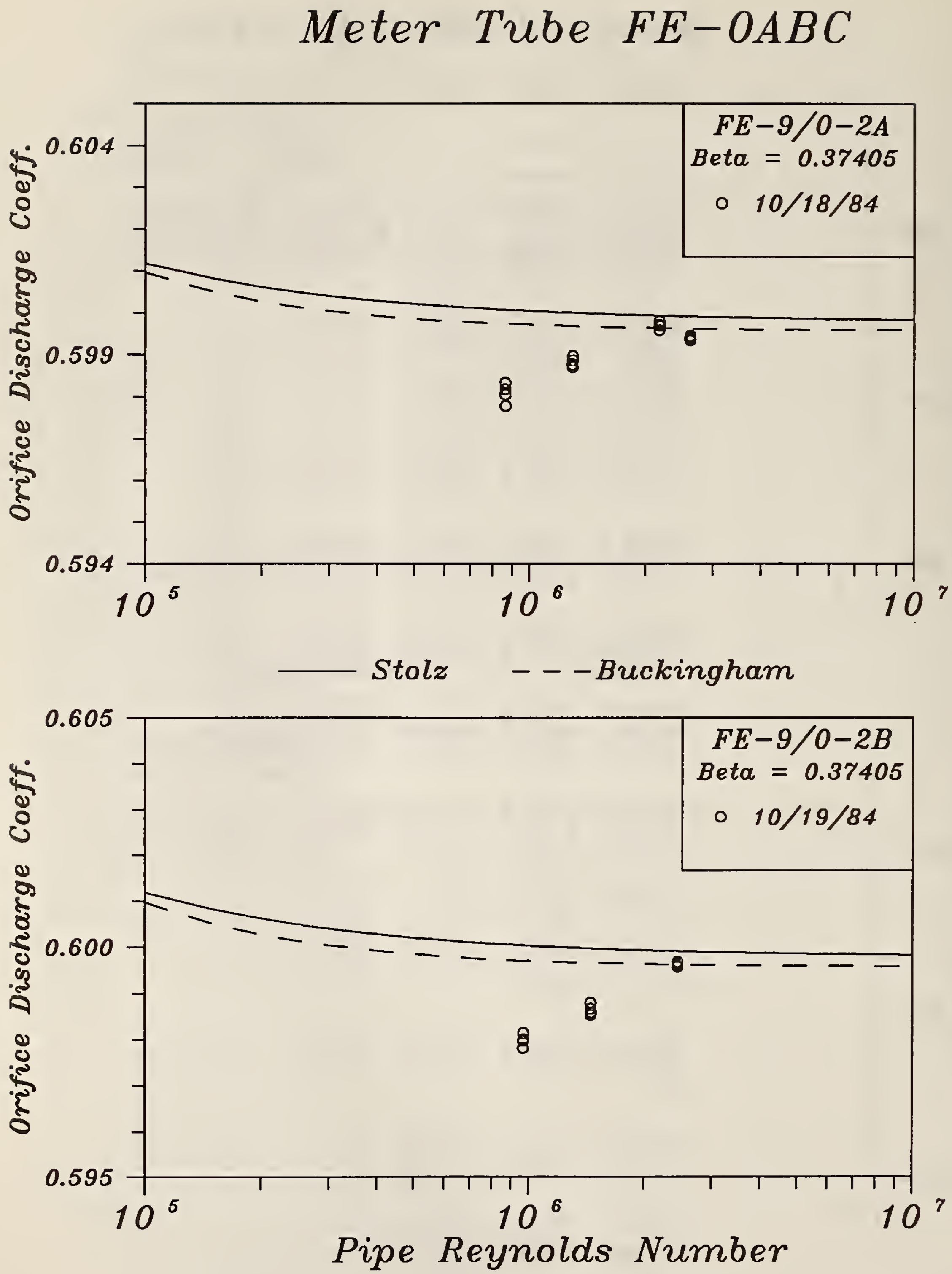


Figure 13B. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

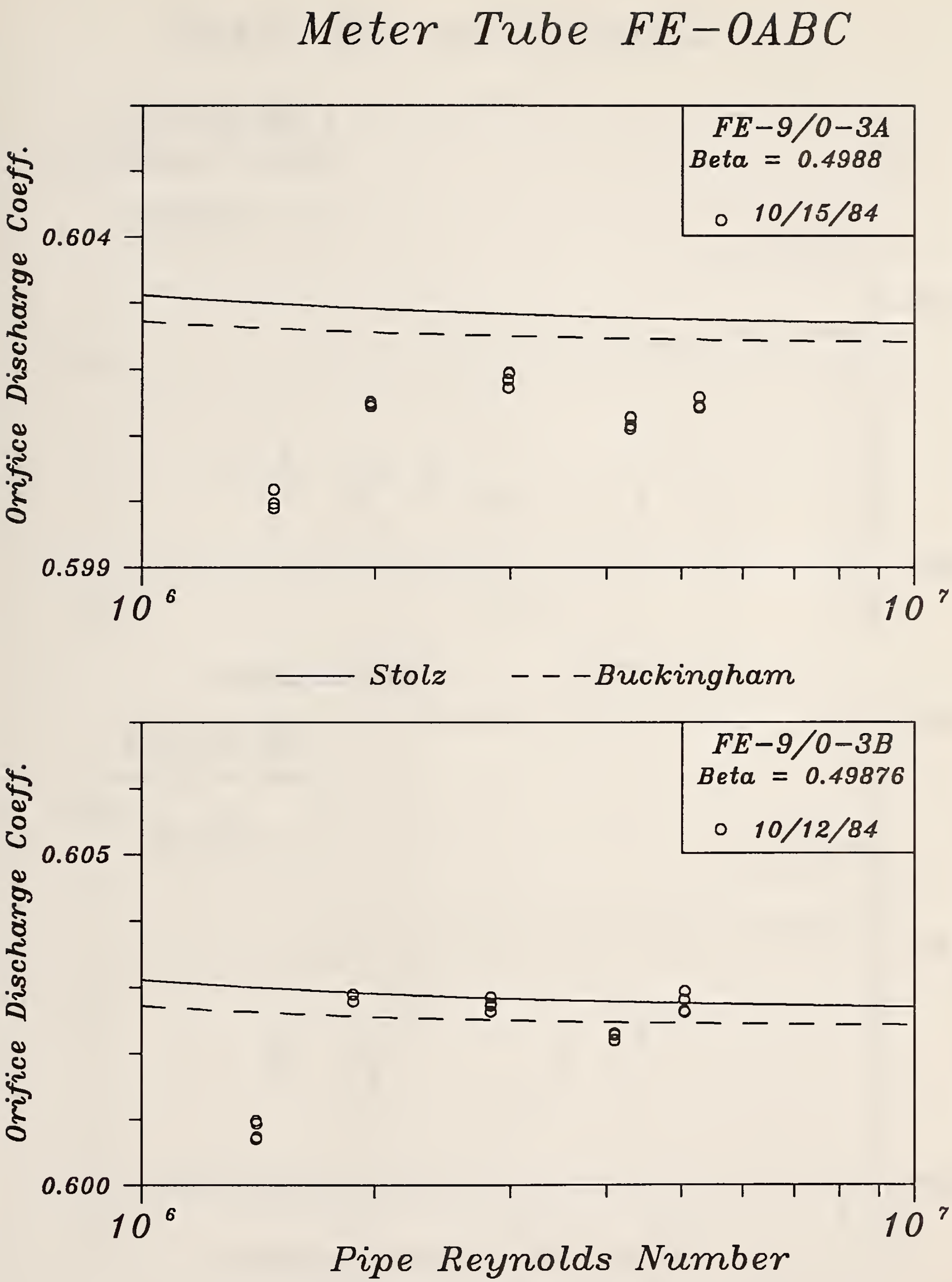


Figure 13C. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

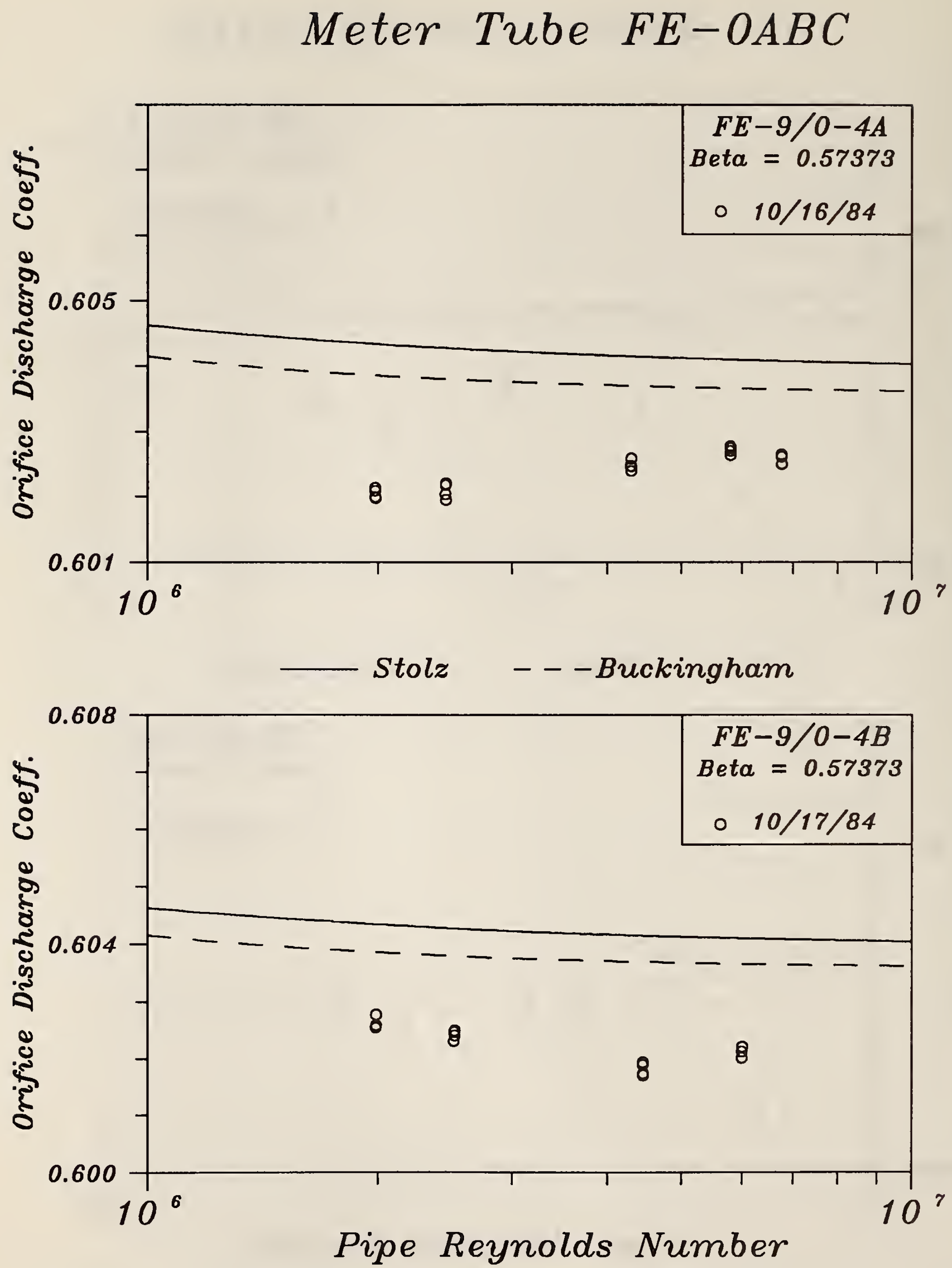


Figure 13D. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

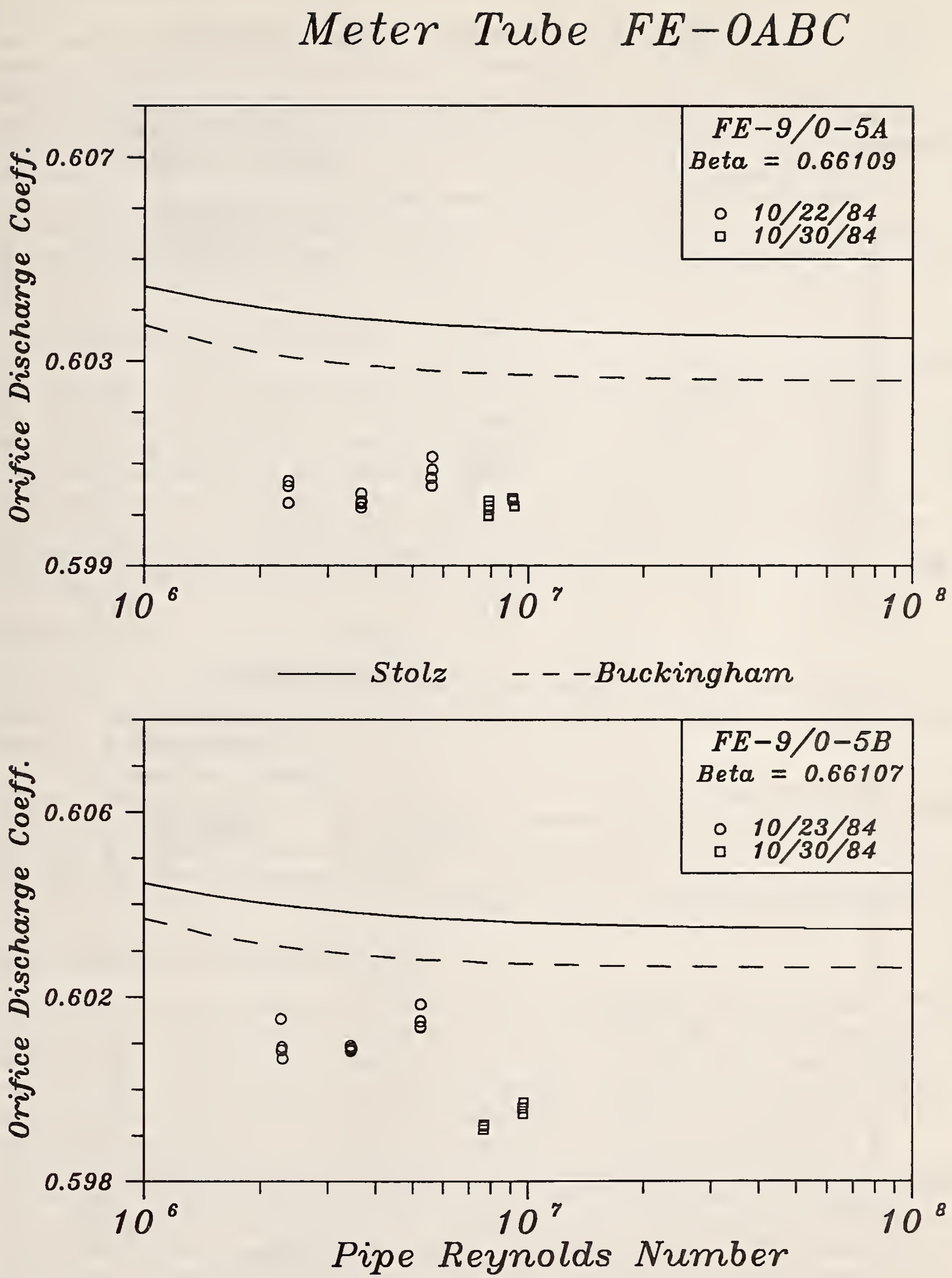


Figure 13E. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

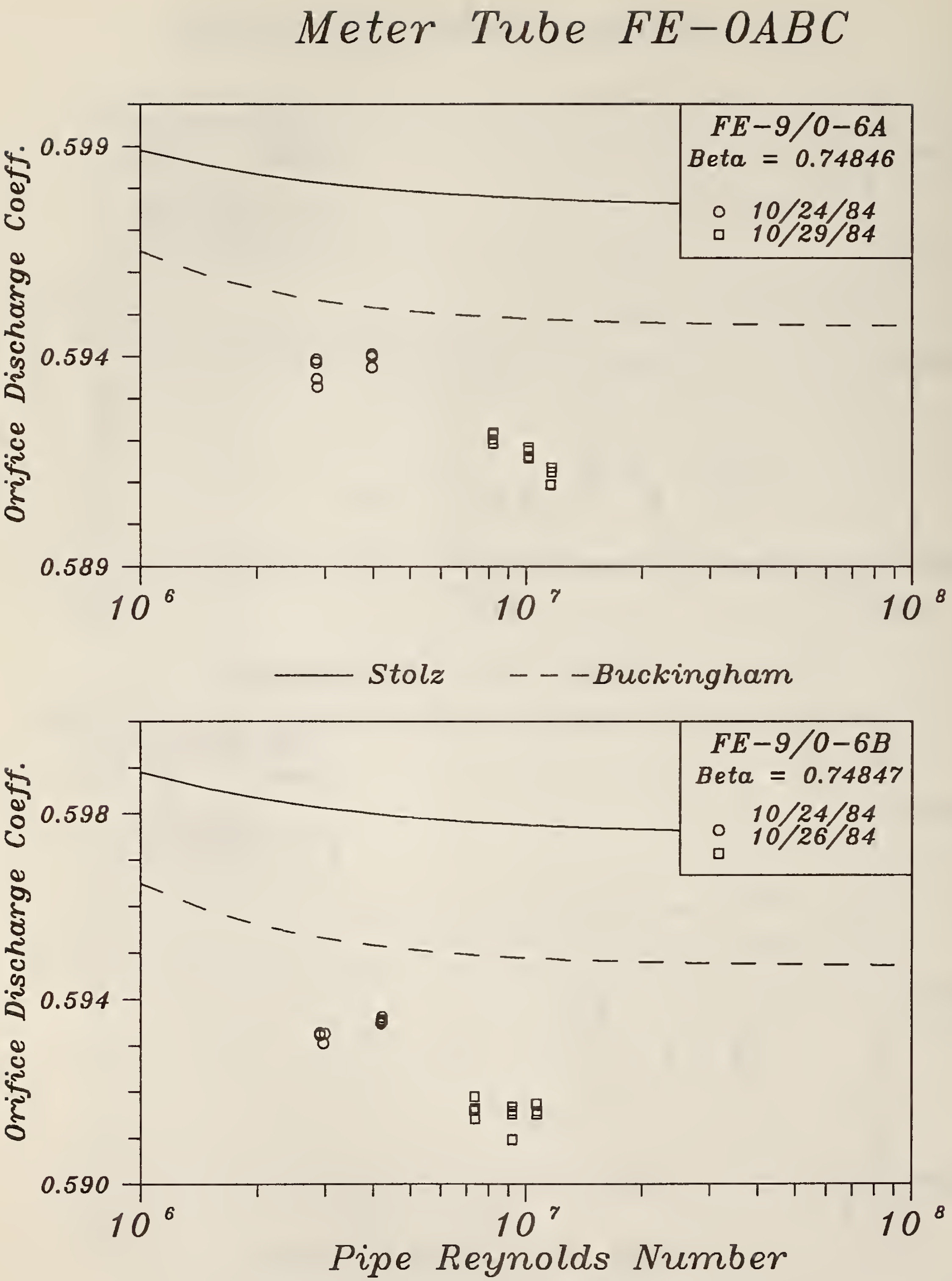


Figure 13F. Discharge coefficient/Reynolds number plots, FE-0ABC, 10-inch meter tube, 12 orifice plates.

D. Test Run Result Analysis and Discussion

The results of the test runs for the four meter tubes involved in these tests are examined and compared for consistency. In doing so the results of the propagation of error analysis are used as a guide to evaluation of expected levels of scatter in the results. It should be noted that the propagation of errors analysis treats those parameters which are known to have an effect on the test results (see Appendix C for a derivation of those parameters). It is possible that other sources of variability may effect the results which were not considered in the propagation of error analysis. It is stressed that the following is not a statistical analysis of the test results.

1. Discussion of Test Results - FE-7ABC

The FE-7ABC orifice meter tube and its associated orifice plates were the first and second set of orifice meters to be tested during the 1984 and 1985 testing seasons, respectively. These orifice meters were the only ones tested in both seasons. The following are brief comments and observations on the character of the results. These are discussed in ascending order of nominal beta ratio. References to Reynolds numbers in the remainder of this discussion refers expressly to the pipe Reynolds number.

Beta Ratio 0.1 - FE-7/8-7A & 7B

Test runs were performed on the 7A plate on one day in 1984. The results of these test runs have a small level of scatter both within and between test groups.

Plate 7B was tested in both 1984 and 1985. The data taken in 1984 agree well with those taken on the 1A plate. The 1985 data shows a considerable degree of scatter although it is still within the bounds of the propagation of errors limits. Test runs 373 - 376 appear to have an unknown difficulty making the discharge values abnormally low (≃ 0.56).

Beta Ratio 0.2 - FE-7/8-8A & 1B

The orifice plate marked FE-7/8-8A is a replacement plate for the original plate marked FE-7/8-1A which was dished early in the program by developing a very high differential pressure across it during initial testing in the intermediate Reynolds number project [1]. The 8A plate was only tested in 1984 at three flow rate settings. Discharge coefficient values for this plate agree well with the character of the C values for the 1B plate. The values for the 1B plate show little dependence on pipe Reynolds number. The scatter in the C values for both plates has a band width of three-quarters to one percent with the exception of test runs 397, taken in 1985, and 507 and 516, taken in 1984, which have an abnormally large variation in the differential pressure and discharge coefficient values. These are offset from those of the remainder of the test run group. The standard deviation of the mean is approximately 5 times that of the other three runs taken in that group.

Beta Ratio 0.375 - FE-7/8-2A & 2B

The 2A plate was tested only in 1984. These test results have a level of reproducibility of approximately 2 parts in 600 or 0.33% and fall below the Buckingham and Stolz correlations by approximately the magnitude of the average random uncertainty. Plate 2B was tested in both 1984 and 1985. A small splitting in the results values may occur at the lowest Reynolds numbers between the two years, but this is within the random variation of the discharge coefficient values with the exception of test runs 472 - 475 in 1985. These discharge coefficient values are inconsistent with the remainder of the plate's results. This fact was noted by the operator and the flow conditions were rerun the same day. The rerun test points are numbers 480 - 483 whose results are consistent with discharge coefficient values observed at other Reynolds numbers.

Beta Ratio 0.5 - FE-7/8-3A & 3B

The 3A plate was run in both operating years. The results from 1984 lie above those obtained in 1985. The difference in C values for the two years is larger than the random component of variation except at the lowest pipe Reynolds numbers, i. e., differential pressures. The difference between the two years results is approximately 4 parts in 600 or 0.66% or greater. The results of test runs 505-509 are not consistent with the remainder of the data on the 3A plate and have not been plotted in the graph for that plate. The operator noted that Gulf Coast gas was in use and that the regulators of the main pipeline were not in service for these runs. The 1984 data taken on both plates is in good agreement and has a between group variation of 1 to 2 parts in 600.

Beta Ratio 0.57 - FE-7/8-4A & 4B

Test runs on plate 4A were taken in the 1984 operating year only and are consistent with expected levels of variation from the propagation of error analysis. Test run data were taken in both years for plate 4B. However, only the two lowest differential pressure points are retained in the final database due to zero drift in the high range differential pressure transducer (see Appendix B). The discharge coefficient values for these two test groups, 206 - 217, agree well with those taken in 1984 on the 4A plate.

Beta Ratio 0.66 - FE-7/8-5A & 5B

Test runs on plate 5A were taken in 1984 only and are self consistent as a set. Data were collected both before and after the change of differential pressure transducers in 1984. Discharge coefficient values obtained on two days, one in 1984, the other in 1985, differ substantially between days. The difference is approximately 10 parts in 600 for the two lowest Reynolds number points, which approximates the sum of the random variations in the values. Even so this difference is large.

Beta Ratio 0.75 - FE-7/8-6A & 6B

Test runs were taken in both years on each plate. The 1984 and 1985 results differ substantially for a given plate, while results for the same year and plates of the same nominal beta ratio agree within the variation predicted by the propagation of errors analysis.

2. Discussion of Test Results - PE-8ABC

The PE-8ABC meter tube was the only nickel-plated meter tube tested in this project. These tests were performed as a check to determine whether the nickel-plated meter tube surface caused any detectable effects on orifice discharge coefficients. The B set of orifice plates were tested at five flow rate settings each in a single series of tests performed on one day with the exception of 2B and 3A which were replicated once. These tests were the last performed in November 1985. The testing was stopped due to cold weather at the test site.

Beta Ratio 0.2 - FE-7/8-1B

The agreement with the results on this plate in the FE-7ABC meter tube are good at the highest three pipe Reynolds number points. The discharge coefficient values obtained at the lowest differential pressure points fall below those taken in the FE-7ABC meter tube, but are in agreement due to the relatively large uncertainty of low differential pressure measurement. Test runs 879 and 884 have considerably larger random uncertainties in the differential pressure relative to the remainder of the test runs on this plate.

Beta Ratio 0.375- FE-7/8-2B

Test runs were taken on two days with flow rates corresponding to 10, 45, and 100 inches of water repeated on the second day. Runs 830 - 833 fall below the remainder of the data. The operator noted this at the time of the tests and repeated this flow rate setting at the end of the day. The results of these reruns agreed more closely with those taken at the other flow rate settings.

Comparison with the results obtained for this plate in the FE-7ABC meter tube shows the low Reynolds number results in PE-8ABC to more closely agree with the 1984 results in FE-7ABC than the 1985 values in the same meter tube. Generally the increasing trend of the discharge coefficient value with pipe Reynolds number in 1985 is seen here except for the low differential pressure values.

Beta Ratio 0.5 - FE-7/8-3A

Test runs were taken on two days over the complete flow rate setting range of approximately 10 to 200 inches of water. The character of the results is one of increasing discharge coefficient value with pipe Reynolds number which is consistent with the behavior of the results obtained on the 3A plate in FE-7ABC in 1985. The highest Reynolds number results agree with the data taken on this plate in the FE-7ABC meter tube in 1984. Generally the agreement between days, meter tubes and years is within that expected from the propagation of errors analysis.

Beta Ratio 0.57 - FE-7/8-4B

The reproducibility at each flow rate setting for these results is quite good. Again the increase in discharge coefficient with pipe Reynolds number is seen for this plate in both meter tubes in which it was tested in 1985.

Beta Ratio 0.66 - FE-7/8-5B

The reproducibility of the results at each flow rate is smaller than that of the between set values. However, the between set scatter in the results is within the uncertainty predicted by the propagation of errors analysis. The magnitude of the between setting variation seen with the plate in PE-8ABC is not reflected in the FE-7ABC results which show little dependence on Reynolds number and are approximately one percent below the Stolz and Buckingham correlations.

Beta Ratio 0.75 - FE-7/8-6B

One day's tests were run with discharge coefficient values showing small dependence on Reynolds number except for the lowest Reynolds number group which lies near the outer bound of random variation as predicted by the propagation of errors analysis. The results taken with this plate in the FE-7ABC meter tube differ by approximately 6 parts in 600 which is at the outer limit of agreement predicted by the propagation of errors analysis.

3. Discussion of Test Results - FE-9ABC

Tests on the FE-9ABC meter tube were performed in 1985 only. The meter tube had been refurbished which resulted in a very smooth meter tube. Tests were performed on 10 of the 12 orifice plates. The results observed for these plates agree within the propagation of errors analysis both internally and between plates. Both show a decrease in discharge coefficient value at the high Reynolds numbers taken on the Amarillo gas stream. However, the variation in the results is within that predicted by the propagation of errors estimates.

Beta Ratio 0.2 - FE-9/0-1B

Discharge coefficient values for this plate show a good degree of consistency with the exception of the test runs taken at pipe Reynolds numbers between 200,000 and 300,000. The range of variation in the values corresponds in most cases to larger differential pressure variation than test runs taken at other Reynolds numbers. Test runs in this Reynolds number range were repeated on several days. The last two days of observations, August 26 and 27, 1985 were somewhat less scattered than the previous day's data, but still showed a larger degree of variation than results taken at the other flow rate points. The variation seen in the Reynolds number range is consistent with the propagation of error analysis.

Many of those test points exhibiting large excursions from the characteristic variation band of discharge coefficient values also have considerably larger variation in the mean differential pressure value, particularly test runs 257, 253, 267, 264, and 247. Discharge coefficient values observed outside the 200,000 to 300,000 region show lower within-group variation than predicted by the propagation of errors analysis. This level of variation is also seen between Reynolds number groupings which occupy a variation band of two to three parts in 600. Generally, little dependence of the discharge coefficient values on pipe Reynolds number is seen, although the lowest Reynolds number points may exhibit a small dependency.

Beta Ratio 0.375 - FE-9/0-2A and 2B

Test runs were performed on one day on the 2B plate and three days on the 2A plate. The results agree between the plates well within the limits of the propagation of errors analysis. It should be noted that test runs on the 2B plate used both types of gas, at times within the same test group. Discharge coefficient values are very consistent in this respect, showing no change with change in gas type.

Beta Ratio 0.5 - FE-9/0-3B

Five days of testing were performed on this orifice meter. As with the 2B plate the gas type was changed during the first test run groups taken. Discharge coefficient values observed at Reynolds numbers above approximately 1,500,000 show little dependence on Reynolds number and have a variation of 1 to 2 parts in 600 across the flow rate range above 15 inches of water. The observations taken at approximately 11 and 15 inches of water consistently fall below those taken at higher differential pressures, although the level of variation is within the propagation of error limits.

Beta Ratio 0.66 - FE-9/0-5B

The dependence of discharge coefficient values on Reynolds number is small. Replication of the observations was not done and the character of the results is similar to the 4A and 4B plates in that a small shift is evident between values obtained on the two gas types. Again the variation is within the limits given by the progation of errors analysis.

Beta Ratio 0.75 - FE-9/0-6A and 6B

Discharge coefficient values decrease somewhat with Reynolds number for both plates. Agreement of the results between the plates is well within the propagation of errors limits as is the within and between group variation. Changes in gas type show no effects.

4. Discussion of Test Results - FE-0ABC

Tests on the FE-0ABC meter tube were performed in 1984 only. The meter tube had been refurbished, resulting in a very smooth meter tube. Tests were performed on 12 orifice plates.

Beta Ratio 0.2 - FE-9/0-1A and 1B

Three flow rate settings only were run on the 1A plate and only one on the 1B plate. The low Reynolds number points agree within the propagation of errors limits.

Beta Ratio 0.375 - FE-9/0-2A and 2B

Observations were taken at five flow rate settings for both plates. The results are consistent between plates and test groups and within propagation of errors limits. Results for both plates indicate a dependence of discharge coefficient on increasing Reynolds number opposite to that predicted by the Stolz and Buckingham correlations.

Beta Ratio 0.5 - FE-9/0-3A and 3B

The results for both plates show a somewhat random pattern of variation which is within the propagation of errors limits. The results for both plates are consistent between themselves and within test groups.

Beta Ratio 0.57 - FE-9/0-4A and 4B

Observations were taken over the full flow rate range, and these agree between the two plates and show a good level of consistency within and between test groups.

Beta Ratio 0.66 - FE-9/0-5A and 5B

Observations were replicated on each plate over the full flow rate range. For both plates the two highest Reynolds number points decrease somewhat relative to the rest of the values. The magnitude of this decrease is less than the propagation of errors limits, but appears to be consistent across the two plates, although observations were taken on the same day for both plates at the high Reynolds number points.

Beta Ratio 0.75 - FE-9/0-6A and 6B

Observations were taken across the full flow rate range, but were not replicated. A decreasing dependence of discharge coefficient with Reynolds number is observed. Consistency in the results between plates is good.

Comparison of Results for FE-9ABC and FE-0ABC

The results obtained for orifice plates tested in both meter tubes show similar results for all plates having a sufficient number of test runs performed to make a reasonable comparison. This represents a comparison between the two years of the work with the corresponding changes in the measurement system and procedures made over the course of the project, and suggests that the measurement systems have performed as expected and do not appear to have contributed anomalies to the results.

VIII. Archiving of the Database

The extent of the complete database generated during the course of this work is quite large. It is stored in computer readable form only and available from either API or NBS. The bulk of the database consists of the differential and static pressure transducer and platinum resistance thermometer observations recorded for each test run, 150 sets of observations. Each observation set contained an observation for each of the thirteen pressure transduction devices and a forward and reverse current resistance value for each of the five thermometers.

The final database contains the normal operational malfunctions and blunders encountered in obtaining any experimental database. These were listed in the inventory given in section VII. The format used in archiving the complete database in computer readable form is described in Appendix G of this report. In archiving the database all of the complete test runs recorded on magnetic diskettes by the data acquisition system are included, i.e., those marked for deletion and those not. Test runs marked for deletion were excluded from the analysis. Test runs interrupted before completion were never recorded by the data acquisition microprocessor. Therefore, these cannot be archived.

IX. Acknowledgments

Many people have contributed their assistance to this project in one way or another. The authors would like to express their gratitude to those who have done so. Specific persons have worked closely with the authors on various aspects of the project: NBS staff, NGPL staff and various individuals associated with the API through its Committee on Petroleum Measurement.

In particular the principal investigator wishes to thank Nancy Skinner, Carol Kimmel, and Monica Mock for their excellent work in preparing intermediate manuscripts and Shirley Losh for completing the final manuscript. Additionally, Dr. R. F. Kayser provided considerable assistance in the editing of the final drafts of this document.

The efforts of various people at NGPL were essential to the completion of this project as a joint one between NGPL and NBS. The authors would like to thank Mr. Gary G. Less for his efforts in working with the authors to achieve a successful conclusion to the project. Various of the staff of the NGPL Station 113, Joliet, IL, contributed time and insight to the startup and operation of the tests during both years of testing. Messrs. J. Jones and G. Buchler provided timely information and expertise during various phases of the project, particularly at those times when diagnostic testing was required. The authors would like to acknowledge the assistance of the two operators of the test loop, Mr. Bud McDaniel in 1984, and Mr. Bob Libershire in 1985. We would particularly like to acknowledge the excellent contribution of Mr. McDaniel, deceased, who operated the test loop in 1984 and assisted with operations in 1985. Mr. McDaniel's constant attention to properly performing the details of the project's operations produced a database with a minimal amount of operator-induced error. Mr. McDaniel's extensive experience in the operation of natural gas pipelines was of much help in completing this project.

The contribution of Drs. K. Starling and J. Savidge of the University of Oklahoma to the analysis portions of the project are gratefully acknowledged for the very timely access provided to the formulations of the equation of state for natural gas mixtures and the associated computer codes. This allowed the computation of results given here to reflect the state-of-the-art in the area of natural gas physical property calculations which have materially improved the quality of the final results of the project. The numerous discussions with Dr. Savidge during code development and debugging were essential to the final completion of this aspect of the work.

Mr. J. Hord, Dr. M. M. Hessel, Dr. J. J. Ulbrecht, and Dr. J. W. Lyons were instrumental in various phases of the project's management and coordination with the API. The principal investigator would like to thank Dr. H. G. Semerjian for his encouragement and many suggestions during the latter phases of the work.

Several individuals outside NBS contributed their time, effort and thought. The membership of the API Orifice Database Steering Committee (OSC) with little exception remained the same throughout the project,

and contributed suggestions, observations, and opinions to the work. The members of the OSC maintained a high level of interest throughout the project and were instrumental in the control of its direction and progress. In particular, Mr. W. A. Fling, as the API Project Manager, maintained close contact with the work in its entirety, closely scrutinized the test run results as they were developed, and was instrumental in identifying malfunctions in the system. Consequently, he and Mr. Less consulted with the NBS principal investigator frequently, and both were instrumental in the solution of several difficulties. The principal investigator would like to acknowledge the efforts of Mr. E. L. Upp and Mr. J. Jones who worked closely with him in identifying difficulties with the differential pressure instrumentation in August 1984. Also, the cooperative spirit and efforts of Mr. C. Britton and Mr. S. Caldwell of CEESI in performing the final diagnostic tests done in October 1985 are much appreciated.

X. References

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APPENDIX A

Descriptions of the API Natural Gas Test Facility
submitted by the
Natural Gas Pipeline Company of America
to
the American Petroleum Institute

Two reports were submitted to the American Petroleum Institute by the Natural Gas Pipeline Company of America describing the natural gas test facility. These are reproduced here in keeping with the intent of NBS and API to document this orifice test program as completely as practicable. Two reports were made describing various aspects of the test facility. No alterations have been made to either report with the exception of placing page numbers on each page to be consistent with the page numbering system of this document.

API NATURAL GAS TEST FACILITY

NATURAL GAS PIPELINE COMPANY OF AMERICA

JOLIET, ILLINOIS

Brief History of Joliet Test Facility

On pipeline systems with high flow rates and high pressures, there has always been the concern of an accurate method of calibration of gas measurement devices under these conditions. In recent years, there has been considerable work on the use of critical flow nozzles as a secondary flow standard for gas meter calibration. The sonic venturi nozzle, as you may be aware, is a development of test work in the aerodynamic industry. Natural Gas Pipeline Company of America has been instrumental in the application of the sonic venturi nozzles as a high pressure calibration standard for turbine and diaphragm meters under operating conditions.

The test site at Joliet, Illinois is set up to meet a variety of needs associated with gas measurements. These included questions about the accuracy of orifice coefficients at high pressure as well as increasing concerns about the calibration of newer flow measuring devices as they come on the market. Of major concern was whether meter manufactures published calibrations of their devices were valid under actual field conditions. The sonic venturi nozzle has proven to be a suitable device to answer these concerns.

When API originated the project to verify or update orifice coefficients, one of their major concerns was verification of the extrapolated orifice equation in the high Reynolds number range. The sonic venturi nozzle approach seemed to be the only secondary standard capable of this possible verification. Natural Gas Pipeline Company of America was chosen by API as the contractor to run the high Reynolds number tests with sonic venturi nozzles for the natural gas phase of the orifice coefficient project at the Joliet, Illinois test facility.

Once the API/NGPLA contract was finalized, NGPLA proceeded to revise the test loop to API specifications in February, 1984.

General Description of Test Facility

The API natural gas test facility for running high Reynolds number tests on 6-inch and 10-inch diameter meter runs against sonic venturi nozzles as a secondary standard is located at Natural Gas Pipeline Company of America's regulator setting near Joliet, Illinois.

The test facility is installed in parallel with NGPLA's mainline regulators and is capable of flow rates in excess of 6,000,000 SCF/hr as presently designed. The pressure cut across the station regulators is sufficient to assure sonic velocities in the application of sonic venturi nozzles. The facility is free of compressor pulsation effects as the nearest reciprocating compressors are approximately 100 miles from the test site.

The test facility is capable of using natural gas from two pipeline systems, each of which has a different gas composition. The typical gas composition of each source is referenced in table number one. All tests run in 1984 were run only from the Gulf Coast source. This was preferable because of the higher total methane and lower nitrogen content. In the 1985 tests, this was not possible and either source of gas was utilized as operating pressures and availability dictated.

	REPRESENTATIVE	ANALYSIS
	Gulf Coast Gas Mol %	Amarillo Gas Mol %
Nitrogen	.30	4.97
Methane	96.30	88.75
Carbon Dioxide	.60	.46
Ethane	1.65	3.97
Propane	.40	1.20
2-Butane	.10	.13
n-Butane	.10	.27
2-Pentane	.05	.07
n-Pentane	.03	.07
Hexanes Plus	.07	.10

Table 1

Modification of the test facility to API specifications was completed in late June for the 1984 series of tests.

1984 System and Piping Configuration

Figure #1 is a general schematic of the 1984 test loop configuration.

Reference Point (1) Figure I

A one million Btu/hr water bath mainline heat exchanger is installed to increase the flowing gas to a temperature above the hydrocarbon dew point to prevent the possible formation of hydrocarbons in the sonic venturi nozzle throat. Gas pressures to the nozzle inlet may vary between 550 psig to 720 psig and nozzle outlet pressures may vary from 385 psig to 415 psig from day to day dependent on NGPLA's load conditions. Flowing gas temperatures are dependent on the capacity of the heat exchanger at a particular flow rate. At low flow rates, a flowing gas temperature of 92°F may be attained, while at the largest flow rates, the maximum flowing gas temperature may be 60°F.

An 89 foot long section of straight pipe precedes the orifice meter test section.

Reference Point (2) Figure I

A 6 X 10 X 6 inch Sprenkle flow conditioner was installed for the 6-inch meter run tests and a 10 X 16 X 10 inch Sprenkle was installed for the 10-inch meter run tests.

Reference Point (3) Figure I

The 6-inch and 10-inch diameter API test meter runs were installed in this location for each of their test periods.

Reference Points (4) (5) (6) Figure I

The secondary section is a four nozzle manifold system. A combination of eleven critical flow venturi nozzles were used ranging in size from 0.094 inches to 2.338 inches, reference table number 2. The five smallest nozzles fit into two inch diameter pipe holders. The six and ten inch holders were removable and could be replaced with any combination of the four 2-inch holders.

Sonic Venturi Nozzle Throat Diameter-Inches	Nozzle Holder Size - Inches
0.095	2
0.1259	2
0.1879	2
0.2491	2
0.3742	2
0.5328	6
0.7537	6
0.064	6
1.375	6
1.945	10
2.330	10

Table #2

Tube bundle type straightening vanes were installed ahead of each sonic nozzle, reference point (4) Figure I

Block and bleed valves installed in each nozzle run assure a positive shut off when a nozzle was taken out of service, reference point (6) Figure I.

Individual flowing gas temperatures were measured upstream of each nozzle with electronic thermo sensors. Orifice meter tube flowing gas temperatures were measured with electronic thermo sensors at the outlet of the downstream spool of the API tube.

Individual static pressures were taken upstream of each sonic nozzle with individual electronic static pressure transducers. Static pressures were taken downstream of each nozzle to assure that sonic flow conditions were present for each data point. The upstream differential pressure tap of both the 6 and 10 inch meter runs was used for the orifice meter static pressure.

Differential pressures across the orifice plate were determined with two 0-30 inch range and two 0-200 inch range Rosemount Model 1151 differential pressure transducers. The two 0-200 inch range transducers were later replaced with two 0-150 inch range transducers with improved resolution resulting.

All electronic transducers were calibrated every morning against standards that had been calibrated or verified by the National Bureau of Standards.

A Ruska Differential Pressure Gauge Model DDR 6000 with a 0-200 inch differential range was utilized as a standard for calibration of the differential pressure transducers.

The static pressure transducers were calibrated against an AMETEK Model HK-1000 Pressure Tester as a standard.

The ENCAL chromatograph was calibrated daily against a standard gas sample prepared by the National Bureau of Standards.

Reference Point (10) Figure I.

A gas sampling probe is installed at this point to supply a continuous on line sample of the flowing gas for the ENCAL gas chromatograph. The sample gas is preheated with a catalytic heater before the pressure is cut to 20 psig at the probe location. The sample line from this point to the ENCAL gas chromatograph is insulated and heat traced it's entire length. A continuous bleed is provided at the chromatograph end to increase the gas velocity in the sample line.

The critical flow venturi nozzles are of the circular arc inlet with no cylindrical throat section. All of the nozzles listed in table number 2 were calibrated at the Colorado Engineering Experiment Station, Inc. (CEESI) Nunn, Colorado under the sponsorship of the Gas Research Institute and with the direct supervision of the National Bureau of Standards.

Reference Points (7) (8) (9) Figure I.

A 12' X 25' instrument building is adjacent to the test facility. One 12 X 12 room for the electronic transducers is equipped for Class II, Division I service. The 12 X 12 room houses the computer, an ENCAL gas chromatograph and the high pressure differential tester. Both rooms are air conditioned.

The entire length of the test loop including approach piping and the nozzle manifold is insulated with one inch thick plastic coated foam rubber type of insulation to reduce ambient temperature changes during each test run.

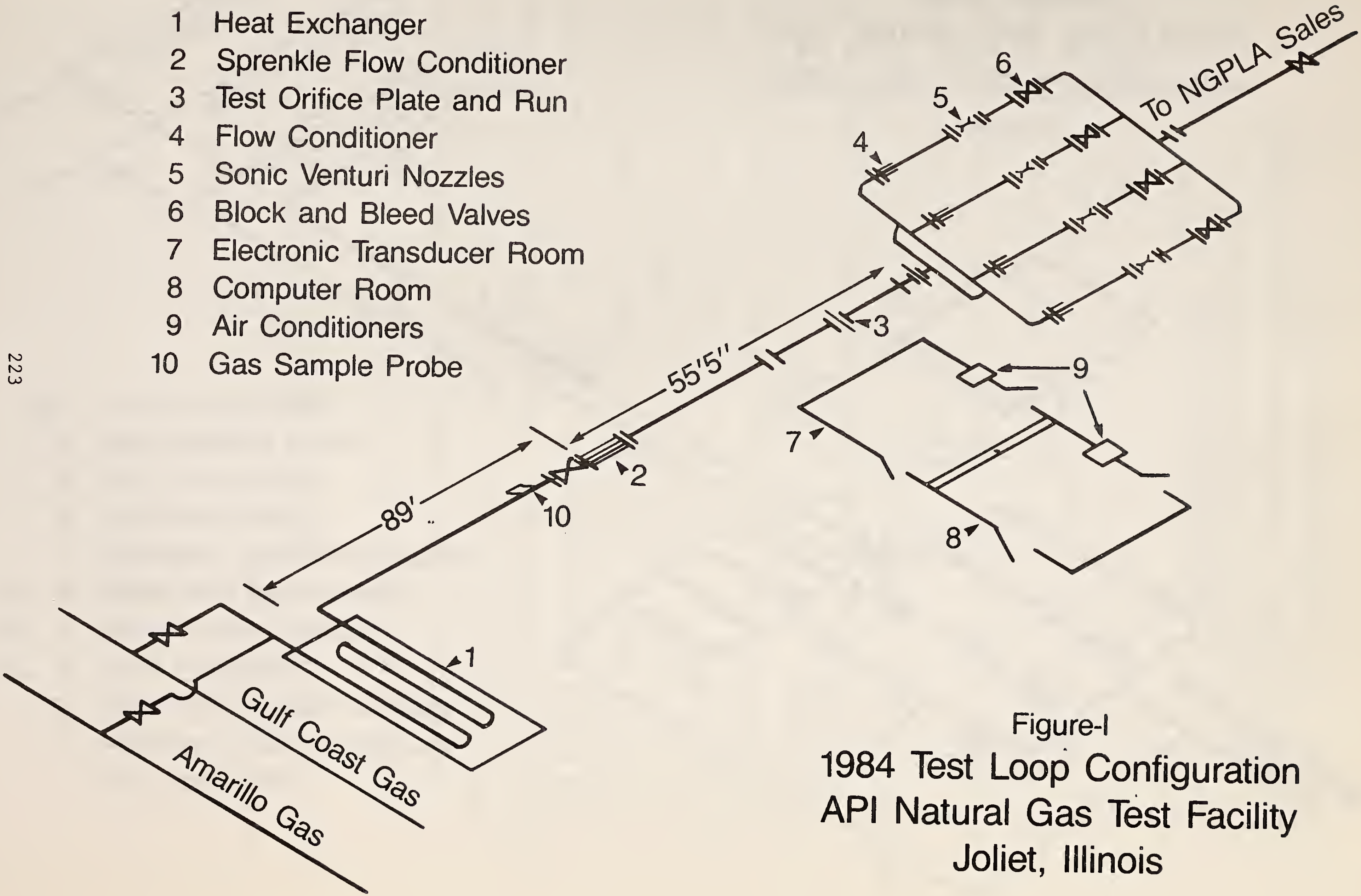
A review of the 1984 data indicated that a repeat of the gas phase of testing should be done in an attempt to improve data scatter at low Reynolds number on the lower beta ratio plates. Figure II is a general schematic of the 1985 test loop configuration. The following modifications were made on the test facility in an attempt to improve the system:

Reference Point (4X) (5X) (6X) (11X) Figure II

A four nozzle manifold of 2-inch holders for the smaller nozzles was fabricated and installed in parallel with the larger four nozzle manifold system. A removable blind plate was installed at point (11X) to isolate the small nozzle manifold from the large nozzle manifold when no nozzles in the large manifold were in service.

The 1984 computer program utilizing a maximum of four static pressure transducers for four sonic nozzles at one time was not changed. For this reason, of the eight nozzles available, flow rates were limited to any combination of nozzles up to a maximum of four nozzles at one time. Since there were only four static pressure transducers available for the eight nozzles, the static pressure sensing lines were manifolded to sense the static pressure of the sonic nozzle in service. For example, static pressure sensing line from the #1 run of small nozzle manifold system was manifolded to the static pressure sensing line from the #1 run of the large nozzle manifold system etc. The same system was also utilized for the temperature sensors by physically connecting the temperature sensor for the nozzle in service to the junction box terminal. Temperature sensors and pressure taps not in service were either disconnected or valved off.

The two 0-150 inch and two 0-30 inch Rosemount pressure transducers were replaced with two 0-200 inch and 0-40 inch Honeywell differential pressure transducers. The new transducer units were internally programmed to compensate for static pressure and ambient temperature effects.



1 Heat Exchanger
2 Sprenkle Flow Conditioner
3 Test Orifice Plate and Run
4 Flow Conditioner
5 Sonic Venturi Nozzles
6 Block and Bleed Valves
7 Electronic Transducer Room
8 Computer Room
9 Air Conditioners
10 Gas Sample Probe

To NGPLA Sales
6
5
4
3
55'5"
9
7
2
89'
10
8
1
Gulf Coast Gas
Amarillo Gas

Figure-I
1984 Test Loop Configuration
API Natural Gas Test Facility
Joliet, Illinois

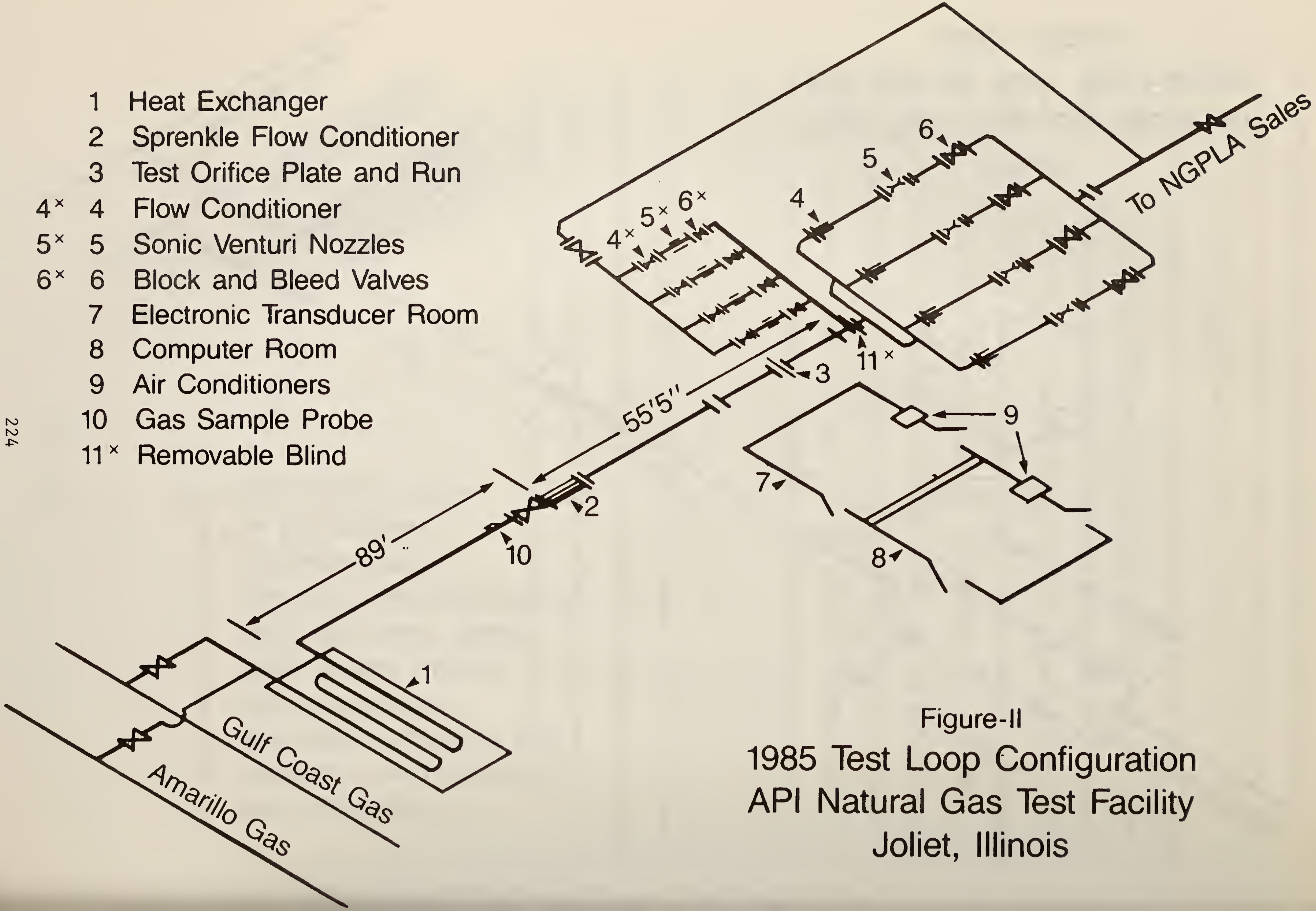

1 Heat Exchanger
2 Sprenkle Flow Conditioner
3 Test Orifice Plate and Run
4× 4 Flow Conditioner
5× 5 Sonic Venturi Nozzles
6× 6 Block and Bleed Valves
7 Electronic Transducer Room
8 Computer Room
9 Air Conditioners
10 Gas Sample Probe
11× Removable Blind
To NGPLA Sales
4× 5× 6×
4
5
6
11×
3
55′5″
2
10
89′
1
9
7
8
Gulf Coast Gas
Amarillo Gas

Figure-II

1985 Test Loop Configuration
API Natural Gas Test Facility
Joliet, Illinois

API NATURAL GAS TEST FACILITY

NATURAL GAS PIPELINE COMPANY OF AMERICA - JOLIET, ILLINOIS

SYSTEM AND PIPING CONFIGURATION DESCRIPTION
1984 and 1985 COMBINED REPORT

General Description

The API natural gas test facility for running high Reynolds number tests on 6-inch and 10-inch diameter meter runs against sonic venturi nozzles as a secondary standard is located at Natural Gas Pipeline Company of America's regulator setting near Joliet, Illinois.

The test facility is installed in parallel with NGPL's mainline regulators and is capable of flow rates in excess of 6,000,000 SCF/hr as presently designed. The pressure cut across the station regulators is sufficient to assure sonic velocities in the application of sonic venturi nozzles. The facility is free of compressor pulsation effects as the nearest reciprocating compressors are approximately 100 miles from the test site.

The test facility is capable of using natural gas from two pipeline systems, each of which has a different gas composition. The typical gas composition of each source is referenced in table number one. All tests run in 1984 at this location were run only from the Gulf Coast source because of its higher total methane and lower nitrogen content. In the 1985 tests, either source of gas was utilized as operating pressures and availability dictated.

The system and piping configuration of the test facility for both the 1984 and 1985 testing periods were basically the same except for the differences as noted in the appendix.

1984 System and Piping Configuration

1. Reference Figure I item 1 & Photo 1.

   A one million Btu/hr water bath mainline heat exchanger is installed to increase the flowing gas to a temperature above the hydrocarbon dew point to prevent the possible formation of hydrocarbons in the sonic venturi nozzle throat. Gas pressures to the nozzle inlet may vary between 550 psig to 720 psig and nozzle outlet pressures may vary from 385 psig to 415 psig from day to day dependent on NGPL's load conditions. Flowing gas temperatures are dependent on the capacity of the heat exchanger at a particular flow rate. At low flow rates, flowing gas temperatures of 92^{o}F may be attained, while at the largest flow rates, the flowing gas temperature may be 60^{o}F.

2. An 89 foot long section of straight pipe precedes the orifice meter test section.

3. Reference Figure 1 item 2 & Figure 8.

   A 6 X 10 X 6 inch Sprinkle flow conditioner was installed for the 6-inch meter run tests and a 10 X 16 X 10 inch Sprinkle was installed for the 10-inch meter run tests.

4. Reference Figure 1 item 3 and Figures 11 and 12 for installation and dimension details of the 6-inch and 10-inch diameter API test meter runs.

5. Reference Figures 1 thru 7 & Photos 1, 7, 8, 9, 10.

   The secondary standard section is a four nozzle manifold system. A combination of eleven critical flow venturi nozzles were used ranging in size from 0.094 inches to 2.338 inches, reference table number 2. The five smallest nozzles fit into two inch pipe holders. The six largest nozzles fit into the six and ten inch diameter holders. The six and ten inch holders may be removed and replaced with any combination of four 2-inch holders illustrated in Figure 7 to accommodate the smaller nozzles.

Block and bleed valves installed in each nozzle run assure a positive shut off when a nozzle is taken out of service.

6. Peference Figures 2, 7 & Photo 9.

   Individual flowing gas temperatures are measured at points "A" for the 6-inch meter run, point "B" for the 10-inch meter run, points "C, D, E and F" for the 6 and 10 inch nozzle holders and point "G" for each of the four 2-inch nozzle holders illustrated in Figure 7.

7. Reference Figures 2 and 7.

   Individual static pressures are taken at points "H, I, J and K" for the 6 and 10 inch nozzle holders and at point "R" for each of the four 2-inch nozzle holders for the upstream nozzle pressure, and at points "L, M, N and P" for the downstream nozzle pressures. The upstream differential pressure tap of both the 6 and 10 inch meter runs is used for the orifice meter static pressure.

8. Reference Figure 1 item 10 & Photo 5:

   A gas sampling probe is installed at this point to supply a continuous on line sample of the flowing gas for the gas chromatograph. The sample gas is preheated with a catalytic heater before the pressure is cut to 20 psig at the probe location. The sample line from this point to the chromatograph is insulated and heat traced it's entire length. A continuous bleed is provided at the chromatograph end to increase the gas velocity in the sample line.

9. Peference Figure 1 item 5, Figures 9, 10 & Photo 6.

   The critical flow venturi nozzles are of the circular arc inlet with no cylindrical throat section. All of the nozzles listed in table number 2 were calibrated at the Colorado Engineering Experiment Station, Inc. (CEESI) Nunn, Colorado under the sponsorship of the Gas Research Institute and with the direct supervision of the National Bureau of Standards.

10. Reference Figure 1 items 7, 8, 9 Figure 13 & Photos 2, 10.

A 12' X 25' instrument building is adjacent to the test facility. One 12 X 12 room for the electronic transducers is equipped for Class II, Division I service. The other 12 X 12 room houses the computer, gas chromatograph and the high pressure differential tester. Both rooms are air conditioned..

11. Reference Photos 4, 8, 9.

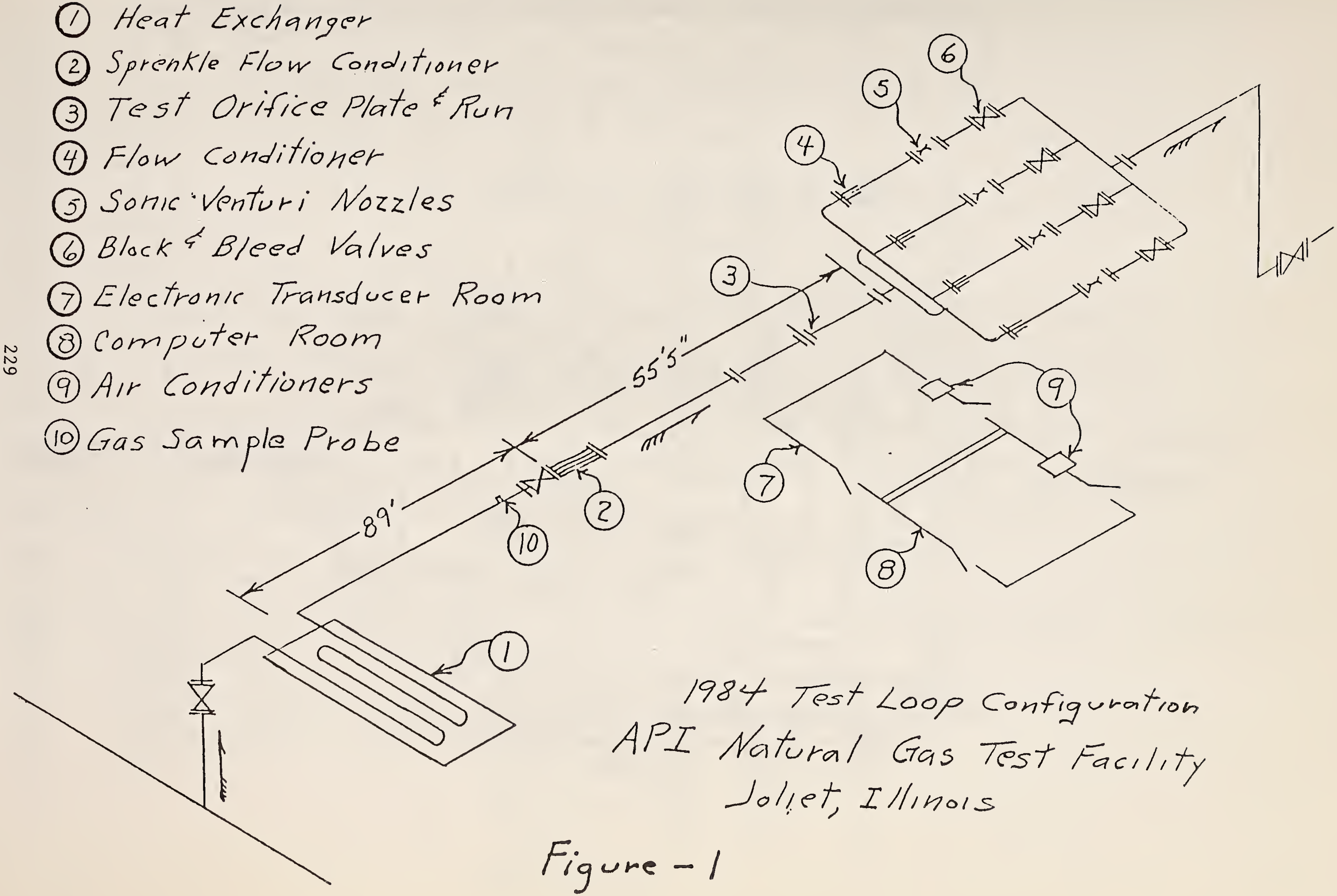
The entire length of the test loop including approach piping and the nozzle manifold is insulated with one inch thick rubber foam plastic coated type of insulation to eliminate ambient temperature changes during each test run.

	REPRESENTATIVE	ANALYSIS
	Gulf Coast Gas Mol %	Amarillo Gas Mol %
Nitrogen	.30	4.97
Methane	96.30	88.75
Carbon Dioxide	.60	.46
Ethane	1.65	3.97
Propane	.40	1.20
2-Butane	.10	.13
n-Butane	.10	.27
2-Pentane	.05	.07
n-Pentane	.03	.07
Hexanes Plus	.07	.10

Table 1

Sonic Venturi Nozzle Throat Diameter-Inches	Nozzle Holder Size - Inches
0.095	2
0.1259	2
0.1879	2
0.2491	2
0.3742	2
0.5328	6
0.7537	6
0.064	6
1.375	6
1.945	10
2.330	10

Table #2


① Heat Exchanger
② Sprenkle Flow Conditioner
③ Test Orifice Plate & Run
④ Flow Conditioner
⑤ Sonic Venturi Nozzles
⑥ Block & Bleed Valves
⑦ Electronic Transducer Room
⑧ Computer Room
⑨ Air Conditioners
⑩ Gas Sample Probe
6
5
4
3
55'5"
9
89'
2
10
7
8
1

1984 Test Loop Configuration
API Natural Gas Test Facility
Joliet, Illinois

Figure - 1

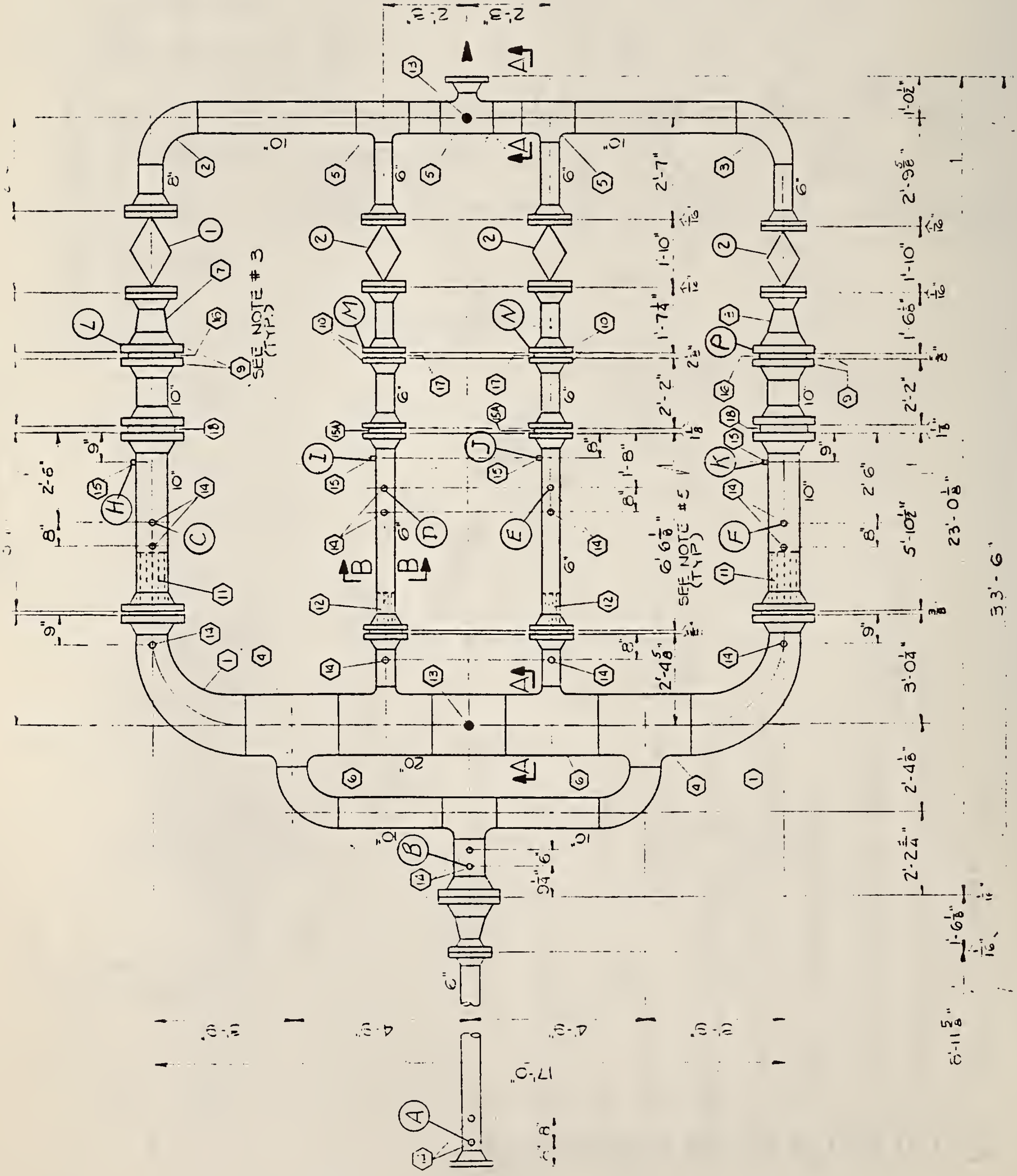

A
B
C
D
E
F
H
I
J
K
L
M
N
P
SEE NOTE # 3 (TYP.)
SEE NOTE # 5 (TYP.)
33'-6"
23'-0 1/8"
5'-10 1/2"
6'-6 1/8"
17'-0"
2'-7"
2'-2"
1'-10"
1'-6 5/8"
1'-7 1/4"
2'-6"
1'-8"
3'-0 1/4"
2'-4 5/8"
2'-2 3/4"
2'-9 5/8"
1'-0 1/2"
5'-11 5/8"
4'-9"
3'-9"
2'-3"
10"
8"
6"
20"
9"
9 1/4"

Figure - 2

PARTIAL MATERIAL LIST FOR TEST LOOP

① 20" × 10" REDUCING ELL.

② 10" × 8" REDUCING ELL.

③ 10" × 6" REDUCING ELL.

④ 20" × 20" × 10" REDUCING TEE

⑤ 10" × 10" × 6" REDUCING TEE

⑥ 20" × 20" × 6" DRAWN NOZZLE - REF. FABRICATION DETAILS DWG. 3-37-C103, ITEM 1

⑦ 10" × 8" REDUCER

⑧ 10" × 6" REDUCER

⑨ 10" - 600# R.F., F.S., W.N. ORIFICE FLANGES - ½" DRILL & ½" N.P.T. TAP, COMPLETE WITH 1¼" DIA. × 0'-9" LG. STUD BOLTS & 1" DIA × 0'-4" JACK SCREWS

⑩ 6" - 600# R.F., F.S., W.N. ORIFICE FLANGES - ½" DRILL & ½" N.P.T. TAP, COMPLETE WITH 1" DIA. × 0'-8¾" LG. STUD BOLTS & 1" DIA. × 0'-3½" LG. JACK SCREWS

⑪ 10" STRAIGHTENING VANES - FLANGE MODEL, CARBON STEEL; DANIEL INDUSTRIES INC. MODEL № 1100F TYPE II, LINE I.D. 10.020" (12¾" RING O.D.)

⑫ 6" STRAIGHTENING VANES - FLANGE MODEL, CARBON STEEL; DANIEL INDUSTRIES INC. MODEL № 1100F TYPE II, LINE I.D. 6.065" (8½" RING O.D.)

⑬ 1" X-HVY. WELDOLET - SEE SECTION A-A

⑭ ¾" - 3000# F.S. FULL COUPLING W/ ¾" X-HVY. BULL PLUG REF. WELD DETAILS DWG. 04-37-A156

⑮ ½" - 3000# F.S. FULL COUPLING W/ ½" X-HVY. BULL PLUG (REF. 04-37-A156)
(15A) SPACER PLATE - 1" THICK FOR 6" - 600# R.F. W.N FLANGE
⑯ SPACER PLATE - ½" THICK FOR 10" - 600# R.F. W.N. ORIFICE FLANGE

⑰ SPACER PLATE - 2" THICK FOR 6" - 600# R.F. W.N. ORIFICE FLANGE
⑱ SPACER PLATE - 1" THICK FOR 10" - 600# R.F. W.N. FLANGE
⑲ SPACER PLATE - 1" THICK FOR 2" - 600# R.F. W.N. FLANGE

Figure - 3

PIPE SCHEDULE

20.000" O.D. × .438" W.T. 5LX40
10.750" O.D. × .365" W.T. GR "B" SMLS.
8.625" O.D. × .322" W.T. GR. "B" SMLS.
6.625" O.D. × .280" W.T. GR. "B" SMLS.
2.375" O.D. & SMALLER TO BE X-HVY. GR. "B" SMLS.

FITTING SCHEDULE

ALL SCREWED FITTINGS TO BE 2000# F.S.
UNLESS OTHERWISE NOTED.
ALL WELD FITTINGS TO MATCH ADJACENT PIPE.

FLANGE SCHEDULE

ALL FLANGES TO BE 600# R.F., F.S., W.N.
UNLESS OTHERWISE NOTED.

VALVE SCHEDULE

① - 8"-600# SEAL VALVE, F.E., W/BLOCK & BLEED FEATURE

② - 6"-600# SEAL VALVE, F.E., W/BLOCK & BLEED FEATURE

③ - 1" BALL VALVE ; W-K-M MODEL#IR-B142-CS-03-S1 WITH LOCTITE COMPOUND

DESIGN PRESSURE: 858 PSIG

DESIGN FACTOR (F): 0.50

Figure-4

NOTES (FABRICATOR)

1. ALL WELDS TO BE FULLY INSPECTED RADIOGRAPHICALLY IN ACCORDANCE WITH THE FOLLOWING FILM REQUIREMENTS
   - CLASS I RADIOGRAPHIC FILM (KODAK TYPE M OR EQ.) AND LEAD SCREENS SHALL BE USED FOR DOUBLE WALL X-RADIOGRAPHY AND ALL GAMMA RADIOGRAPHY.
   - CLASS II RADIOGRAPHIC FILM (KODAK TYPE AA OR EQ.) AND LEAD SCREENS SHALL BE USED FOR SINGLE WALL RADIOGRAPHY.

   SINGLE WALL X-RADIOGRAPHY SHALL BE THE PREFERRED METHOD OF EXAMINATION.

2. ALL PIPING TO BE HYDROSTATICALLY TESTED AS FOLLOWS:
   1287 PSIG MIN.; 1337 PSIG MAX.
   DURATION - 4 HOURS
   MEDIUM - WATER

3. ALL ORIFICE FLANGES SHALL BE ORIENTED WITH THE PORTS IN THE THREE- AND NINE-O'CLOCK POSITIONS.

4. ALL TAPS IN TEST LOOP SHALL BE DRILLED THRU. AT POINT OF BREAKTHROUGH, ALL EDGES SHALL BE DEBURRED AND LIGHTLY ROUNDED TO A RADIUS NOT EXCEEDING 0.1 DIAMETERS OF THE TAP.

5. SPOOL PIECES CONTAINING 6" AND 10" STRAIGHTENING VANES (ITEMS ⑪ & ⑫) SHALL EACH HAVE AN INTERIOR SURFACE ROUGHNESS HEIGHT WHICH DOES NOT EXCEED 10^{-4} DIAMETERS. CIRCULARITY OF EACH SPOOL SHALL NOT DEVIATE BY MORE THAN 0.01 DIAMETERS.

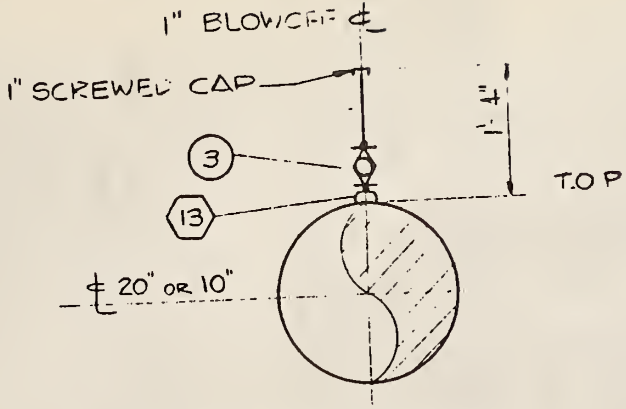
6. ALL EXTERIOR SURFACES TO BE PAINTED WITH RED OXIDE PRIMER.

7. DESIGN TEMPERATURE: 100° F

8. FABRICATION TO BE IN ACCORDANCE WITH AGA GAS COMMITTEE REPORT NO. 3 (LATEST REVISION)

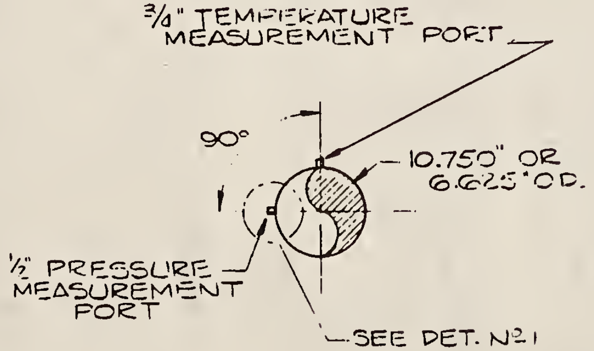
9. STRESS RELIEF: NOT REQ'D.

Figure-5


1" BLOWOFF ℄
1" SCREWED CAP
3
13
1¼"
TOP
℄ 20" OR 10"

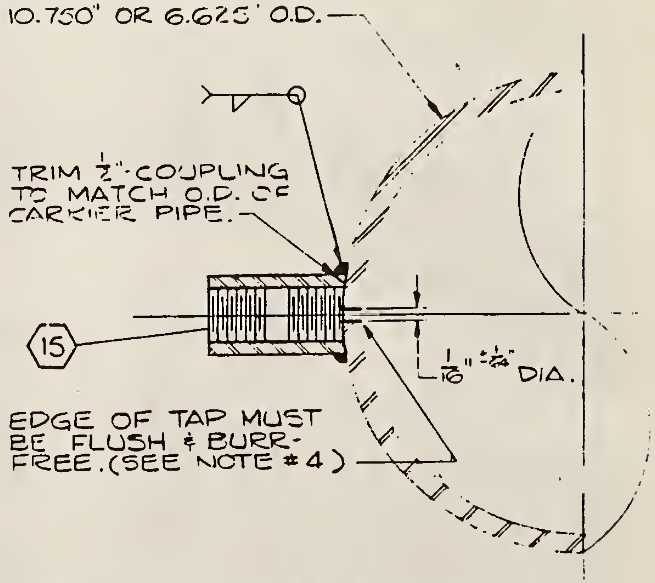
SECTION A-A

TYPICAL (2) PLACES


¾" TEMPERATURE MEASUREMENT PORT
90°
10.750" OR 6.625" O.D.
½" PRESSURE MEASUREMENT PORT
SEE DET. No 1

SECTION B-B

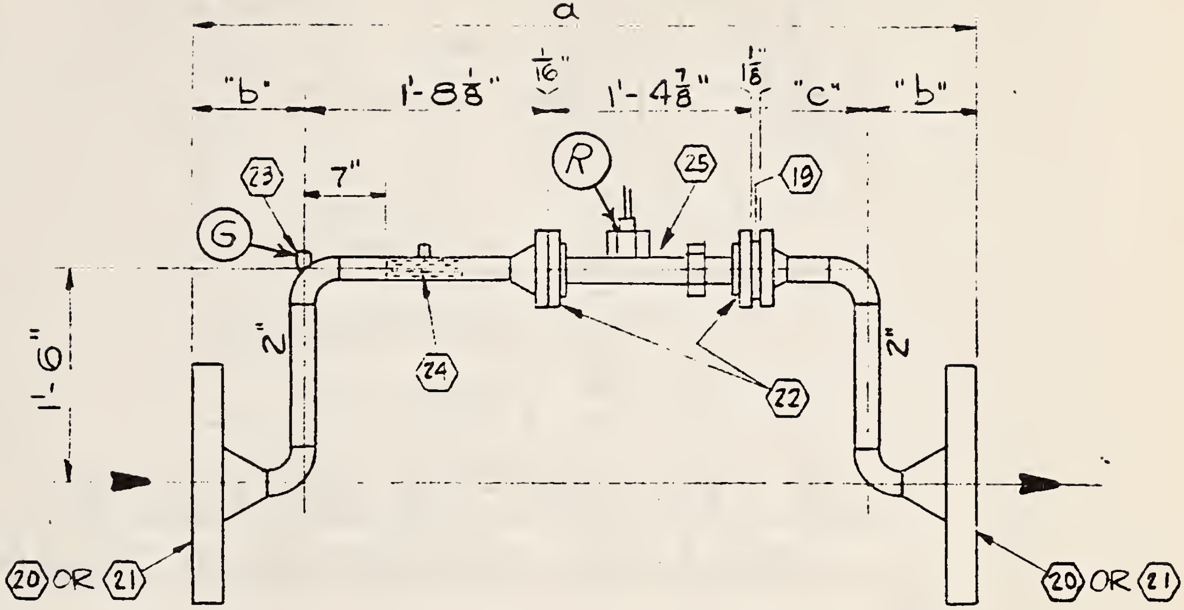
PORT LOCATIONS
TYPICAL (4) PLACES


10.750" OR 6.625" O.D.
TRIM ½" COUPLING TO MATCH O.D. OF CARRIER PIPE.
15
1/16" ±1/64" DIA.
EDGE OF TAP MUST BE FLUSH & BURR-FREE. (SEE NOTE # 4)

DETAIL No 1

PRESSURE TAP DETAIL
TYPICAL (4) PLACES

Figure-6


"a"
"b"
1'-8 1/8"
1/16"
1'-4 7/8"
1/8"
"c"
"b"
7"
23
G
R
25
19
2"
24
22
2"
1'-6"
20 OR 21
20 OR 21

	"a"	"b"	"c"	FLANGE SZ.
6" RUN	6'-7 1/2"	7 7/8"	2'-1 9/16"	18
10" RUN	5'-11 7/8"	9 1/4"	1'-3 5/16"	19

20 —— 2" x 14" O.D. (600 #) R.F., F.S., W.N. REDUCING FLANGE

21 —— 2" x 20" O.D. (600 #) R.F., F.S., W.N. REDUCING FLANGE

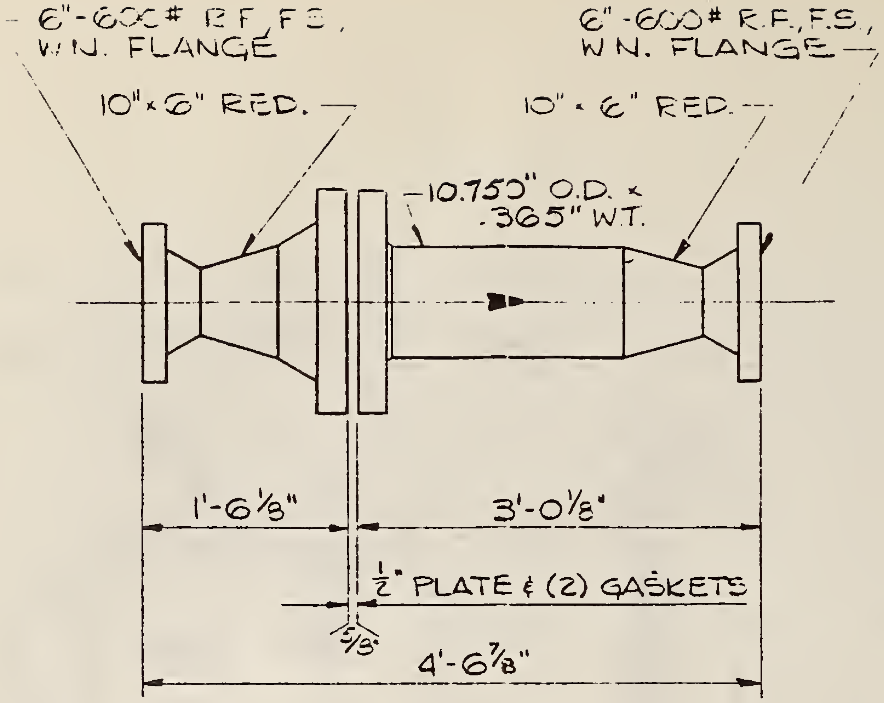
22 —— 2" - 600 # R.F., F.S., THREADED FLANGE

23 —— 3/4" X-HVY. THREADED ELBOLET W/ 3/4" X-HVY. BULL PLUG

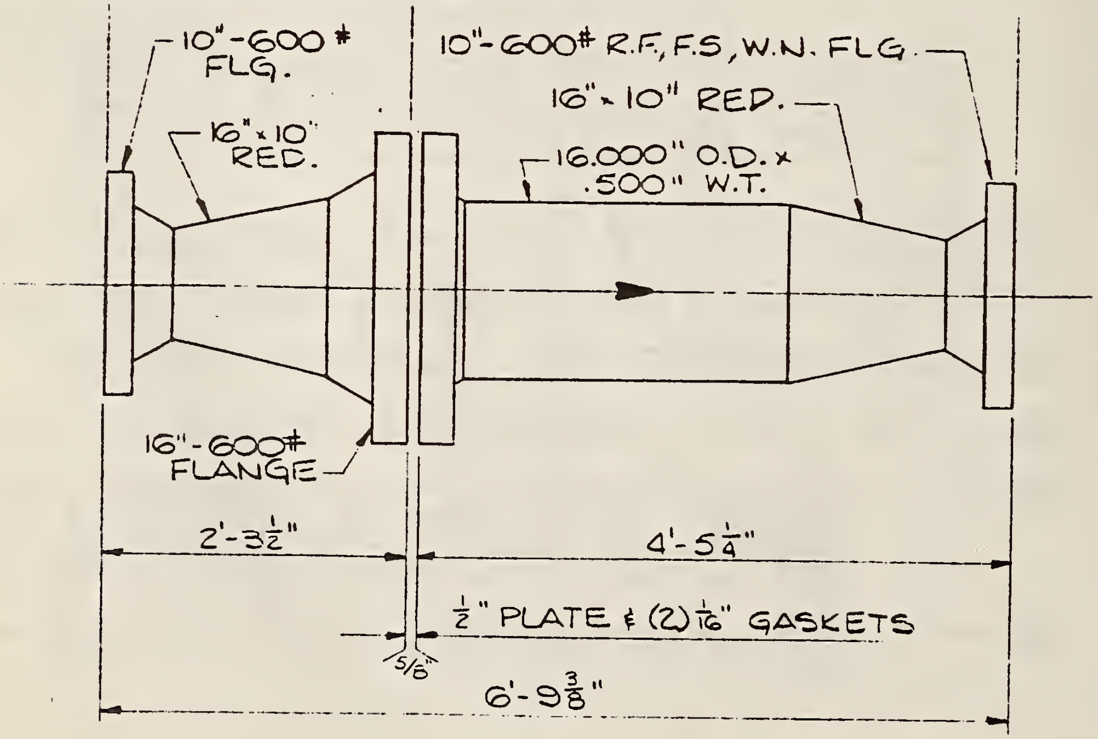
24 —— 2" STRAIGHTENING VANES - IN LINE MODEL,
CARBON STEEL; DANIEL INDUSTRIES INC.
MODEL Nº 1100L TYPE I, LINE I.D. 1.939"
REF. INSTALLATION DETAIL DWG. 03-27-C23

25 —— 2" SONIC FLOW NOZZLE & FLOW PROVER HOLDER-
SUPPLIED BY API.

Figure - 7

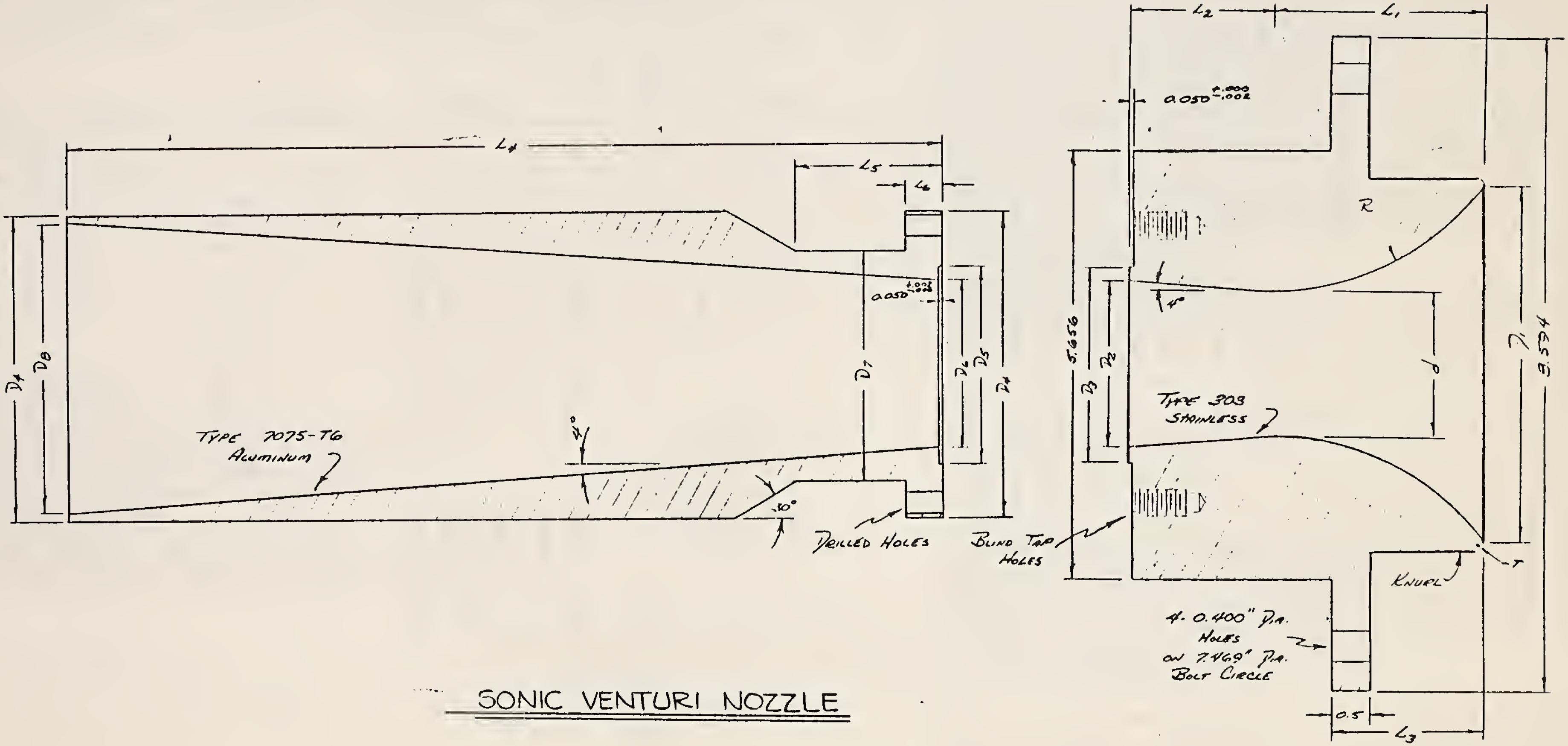

6"-600# R.F., F.S., W.N. FLANGE
6"-600# R.F., F.S., W.N. FLANGE
10" x 6" RED.
10" x 6" RED.
10.750" O.D. x .365" W.T.
1'-6 1/8"
3'-0 1/8"
1/2" PLATE & (2) GASKETS
5/8"
4'-6 7/8"

6" x 10" SPRENKLE PLATE HOLDER ASSEMBLY - PLAN


10"-600# FLG.
10"-600# R.F., F.S, W.N. FLG.
16" x 10" RED.
16" x 10" RED.
16.000" O.D. x .500" W.T.
16"-600# FLANGE
2'-3 1/2"
4'-5 1/4"
1/2" PLATE & (2) 1/16" GASKETS
5/8"
6'-9 3/8"

10" x 16" SPRENKLE PLATE HOLDER ASSEMBLY - PLAN

Figure - 8


L4
L5
L6
D4
D8
D7
D6
D5
D4
0.050 +.025 −.025
4°
10°
TYPE 7075-T6 ALUMINUM
DRILLED HOLES
BLIND TAP HOLES
L2
L1
0.050 +.000 −.002
R
4°
5.656
D3
D2
d
D1
3.534
TYPE 303 STAINLESS
T
KNURL
4- 0.400" DIA. HOLES ON 7.469" DIA. BOLT CIRCLE
0.5
L3

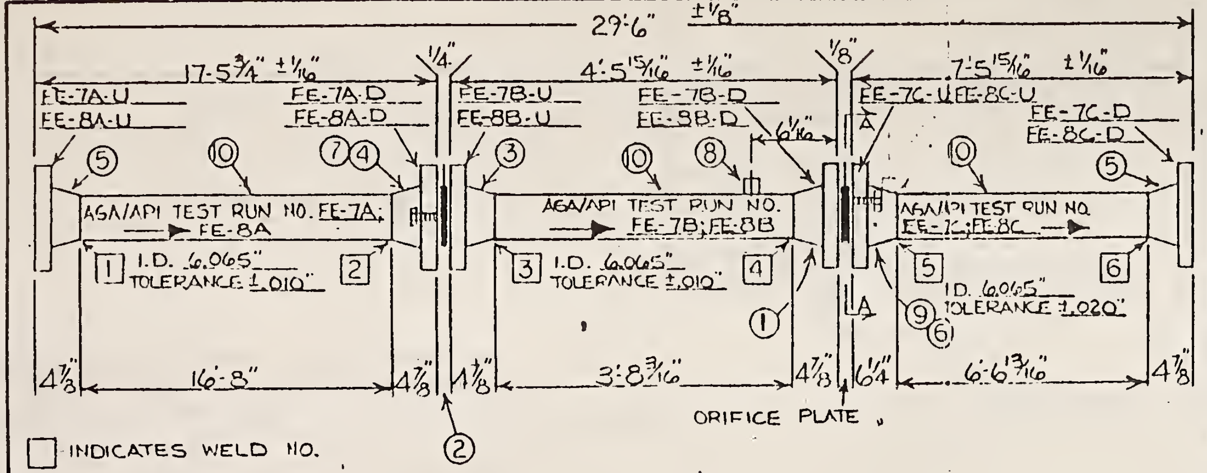
SONIC VENTURI NOZZLE

Figure-9

d	R	D_1	D_2 Approx	D_3 +.000 −.001	L_1	L_2	L_3	r Approx	Blind Tap No. of Holes	Blind Tap Size	Blind Tap Dia of B.C.
.533	.969	1.286	.603	1.000	.766	.533	1.0	.03	4	10-24	1.60
.754	1.371	1.819	.853	1.200	1.084	.754	1.0	.04	4	10-24	2.10
1.065	1.936	2.569	1.205	1.600	1.581	1.065	1.0	.05	4	10-24	2.70
1.375	2.500	3.317	1.555	2.000	1.977	1.375	2.0	.07	4	10-24	2.70
1.945	3.536	4.691	2.200	2.600	2.797	1.945	2.0	.10	6	1/4-20	3.5
2.330	4.236	5.620	2.635	3.000	3.351	2.330	2.0	.12	6	1/4-20	4.50
2.935	5.336	7.079	3.320	4.000	4.221	2.935	2.0	.15	6	1/4-20	5.50

D_4	D_5 +.001 −.000	D_6 D_2 +.005 −.000	D_7	D_8 Approx	L_4	L_5	L_6	Hole Size No of Holes	Hole Size Size	Hole Size Dia of B.C.
2.00	1.000		1.25	1.050	3.248	1.00	0.375	4	.220	1.60
2.50	1.200		1.75	1.456	4.574	1.00	0.375	4	.220	2.10
3.00	1.600		2.25	2.093	6.440	1.50	0.50	4	.220	2.70
3.00	2.000		2.25	2.709	8.300	1.50	0.50	4	.220	2.70
4.00	2.600		3.00	3.832	11.72	2.0	0.75	6	.280	3.50
5.00	3.000		4.00	4.590	14.03	2.0	0.75	6	.280	4.50
5.65	4.000		5.00	5.420	15.12	2.0	0.75	6	.280	5.50

Figure-10


29'-6" ±1/8"
17-5¾" ±1/16"
4'-5 15/16" ±1/16"
7'-5 15/16" ±1/16"
1/4"
1/8"
FE-7A-U
FE-8A-U
FE-7A-D
FE-8A-D
FE-7B-U
FE-8B-U
FE-7B-D
FE-8B-D
FE-7C-U FE-8C-U
FE-7C-D
FE-8C-D
6 1/16"
A
AGA/API TEST RUN NO. FE-7A; FE-8A
AGA/API TEST RUN NO. FE-7B; FE-8B
AGA/API TEST RUN NO. FE-7C; FE-8C
I.D. 6.065" TOLERANCE ±.010"
I.D. 6.065" TOLERANCE ±.010"
I.D. 6.065" TOLERANCE ±.020"
1
2
3
4
5
6
7
8
9
10
4 7/8
16'-8"
3'-8 3/16"
6 1/4"
6'-6 13/16"
ORIFICE PLATE

☐ INDICATES WELD NO.

ITEM	QUAN	HEAT NO.	DESCRIPTION
1	1		6"-600# RFWN C.S. ORIF. FLG. 6.065" I.D. SPCL. TAPS W/STG'D. J.S. MACH. F/'O'-RING & K.O. DOWELS PER DWG. D-1479
2	1		6"-600# 304SS SPACER PLATE 1/4" TK.
3	1		6"-600# RFWN C.S. FLG. 6.065" I.D. MACH. F/ O-RING & K.O. DOWELS PER DWG. B-7438
4	1		6"-600# RFWN C.S. FLG. 6.065" I.D. W/(2) 3/4"x 4" J.S. MACH. F/ O RING & K.O. DOWELS PER DWG. B-7438
5	2		6" 600# RFWN C.S. FLG. 6.065" I.D.
6	12		1"x8½" STUDS & NUTS W/(2) 1"x 4" J.S.
7	12		1"x 7" STUDS & NUTS
8	1		½"-3000# HALF CPLG. - DO NOT DRILL THRU - PRESSURE TAP (RADIUS)
9	1		6-600# RFWN ORIF. FLG. 6.065" I.D. SPCL. TAPS W/ STG'D. J.S. W/ O-RING & K.O. DWLS W/ ½" RADIUS TAP NOT DRILLED THRU PER DWG. D-1479
10			6" SCH. 40 A-106 GR. B TUBG. 6 5/8" O.D. x .280" W.T.

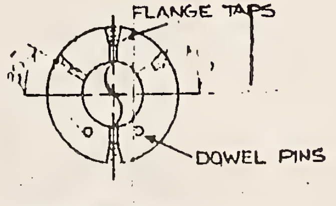
SPECIAL SERVICES

(1) 100% X-RAY PER API-1104
(2) SANDBLAST & PAINT W/ DIMETCOTE #3
(3) HYDROTEST FOR 4 HRS. AT 2175 PSIG - CHARTS REQ'D.

SEP 19 1978

GENERAL NOTES

(1) CAD. PLATED S & N
(2) PAINT STENCIL FLOW ARROWS & LABELS ON EACH SECTION AS SHOWN.
(3) SPECIAL CALIBRATION SHEETS REQ'D.
(4) SURFACE FINISH CHECK TO BE MADE AT EACH POINT OF MIKING
(5) USE SELECT GRADE PIPE. 'Q.C.' TO APPROVE ALL MAT'LS. BEFORE USE.
(6) PROTECT FLG'S. W/ PLYWOOD F/ SHIPMENT
(7) FOR ORIFICE FLANGE DETAILS SEE DWG. D-1479


FLANGE TAPS
DOWEL PINS

SECTION 'AA'

CUSTOMER: AMERICAN GAS ASSOCIATION
P.O. NO.: 1584
DANIEL SO# 19288
TUBE NO 17766, 17767
W.O. NO 47876

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SYM	REVISION	DATE	BY

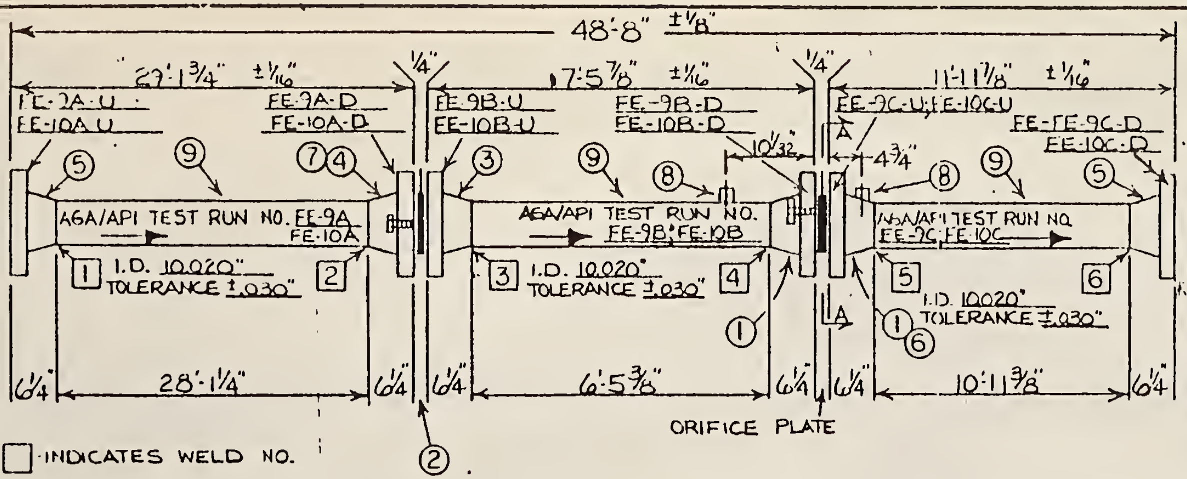
DANIEL INDUSTRIES, INC.
9720 KATY ROAD
HOUSTON, TEXAS 77024

6" AGA/API METER RUN
FOR TEST

DRN CW
APPVD JB
SUPERSEDES DWG. NO.
SUPERSEDED BY DWG. NO.
DATE 8-23-78
CERTIFIED CORRECT BY
SCALE NONE
BS-0258-4

(BRUNING)

Figure -11


48'-8" ±1/8"
27'-1 3/4" ±1/16"
7'-5 7/8" ±1/16"
11'-11 7/8" ±1/16"
1/4"
1/4"
FE-9A-U
FE-10A-U
FE-9A-D
FE-10A-D
FE-9B-U
FE-10B-U
FE-9B-D
FE-10B-D
FE-9C-U; FE-10C-U
FE-FE-9C-D
FE-10C-D
10 1/32"
4 3/4"
A
A
AGA/API TEST RUN NO. FE-9A FE-10A
AGA/API TEST RUN NO. FE-9B; FE-10B
AGA/API TEST RUN NO. FE-9C; FE-10C
I.D. 10.020" TOLERANCE ±.030"
I.D. 10.020" TOLERANCE ±.030"
I.D. 10.020" TOLERANCE ±.030"
①
②
③
④
⑤
⑥
⑦
⑧
⑨
1
2
3
4
5
6
6 1/4"
28'-1 1/4"
6'-5 3/8"
10'-11 3/8"
ORIFICE PLATE

☐ INDICATES WELD NO.

ITEM	QUAN	HEAT NO.	DESCRIPTION
1	2		10"-600# RFWN C.S. ORIF. FLG. 10.020" I.D. SPCL. TAPS W/ STG'D. J.S. MACH. F/ O-RING & K.O. DWLS. PER DWG. D-1480
2	1		10" 600# 304SS SPACER PLATE 1/4" TK.
3	1		10"-600# RFWN C.S. FLG. 10.020" I.D. MACH. F/ O RING & K.O. DWLS. PER DWG. B-1439
4	1		10"-600# RFWN C.S. FLG. 10.020" I.D. W/ (2) 1" x 5 1/2" J.S. MACH F/ O-RING & K.O. DWLS. PER DWG B-1439
5	2		10"-600# RFWN C.S. FLG. 10.020" I.D.
6	16		1 1/4" x 9" S & N W/(2) 1" x 5 1/2" J.S.
7	16		1 1/4" x 9" S & N
8	2		1/2"-3000# HALF CPLG. PRESSURE TAP (RADIUS) DO NOT DRILL THRU
9			10" SCH. 40 A-53 GR.B PIPE 10 3/4" O.D. x .365" W.T.

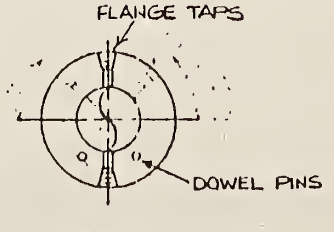
SPECIAL SERVICES

(1) 100% X-RAY PER API-1104
(2) SANDBLAST & PAINT WITH DIMETCOTE #3
(3) HYDROTEST FOR 4 HRS. AT 2175 PSIG - CHARTS REQ'D.

SEP 19 1978

GENERAL NOTES

(1) CAD. PLATED S & N
(2) PAINT STENCIL FLOW ARROWS & LABELS ON EACH SECTION AS SHOWN.
(3) SPECIAL CALIBRATION SHEETS REQ'D.
(4) SURFACE FINISH CHECK TO BE MADE AT EACH POINT OF MIKING
(5) USE SELECT GRADE PIPE. 'Q.C.' TO APPROVE ALL MAT'LS. BEFORE USE:
(6) PROTECT FLG'S. W/ PLYWOOD F/ SHIPMENT
(7) FOR ORIFICE FLANGE DETAILS SEE DWG. D-1480


FLANGE TAPS
DOWEL PINS

SECTION 'AA'

CUSTOMER: AMERICAN GAS ASSOCIATION
P. O. NO.: 1584
DANIEL SO# 19288
TUBE NO 04314, 04315
W.O. NO 47877

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SYM	REVISION	DATE	BY

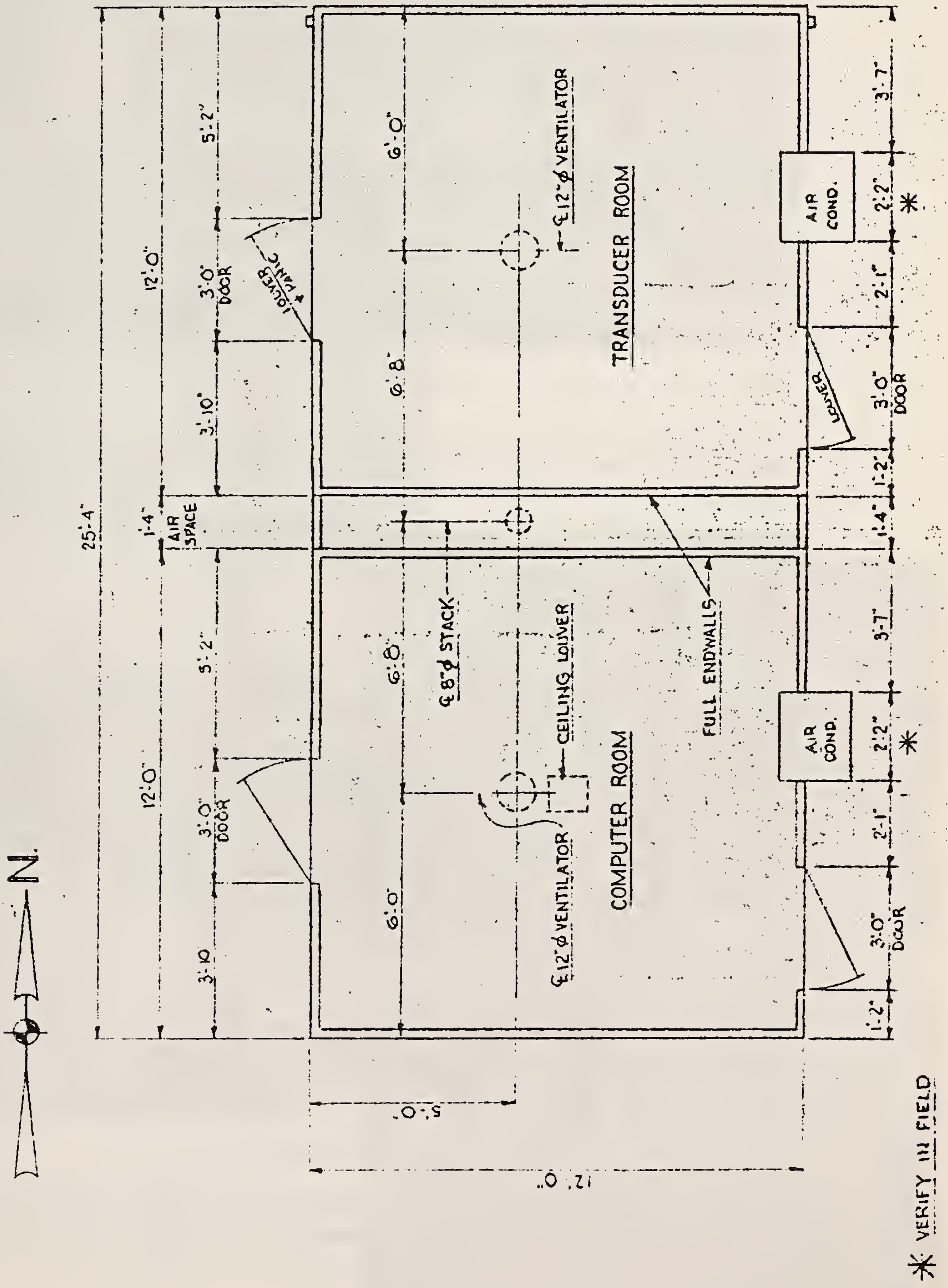
DANIEL INDUSTRIES, INC.
9720 KATY ROAD
HOUSTON TEXAS 77024

10" AGA/API METER RUN
FOR TEST

DRN	APPVD	SUPERSEDES DWG NO.	SUPERSEDED BY DWG NO.
CW	JB		
DATE 8-23-78		CERTIFIED CORRECT BY	BS-0258-5
SCALE NONE			

BRUNING

Figure-12


N
25'-4"
12'-0"
1'-4" AIR SPACE
12'-0"
3'-10"
3'-0" DOOR
5'-2"
3'-10"
3'-0" DOOR
5'-2"
LOUVER & VANE
6'-0"
6'-8"
6'-8"
6'-0"
℄ 8"φ STACK
CEILING LOUVER
℄ 12"φ VENTILATOR
℄ 12"φ VENTILATOR
COMPUTER ROOM
TRANSDUCER ROOM
FULL ENDWALLS
AIR COND.
AIR COND.
LOUVER
1'-2"
3'-0" DOOR
2'-1"
2'-2"
3'-7"
1'-4"
1'-2"
3'-0" DOOR
2'-1"
2'-2"
3'-7"
*
*
5'-0"
12'-0"
* VERIFY IN FIELD

PLAN

Figure-13

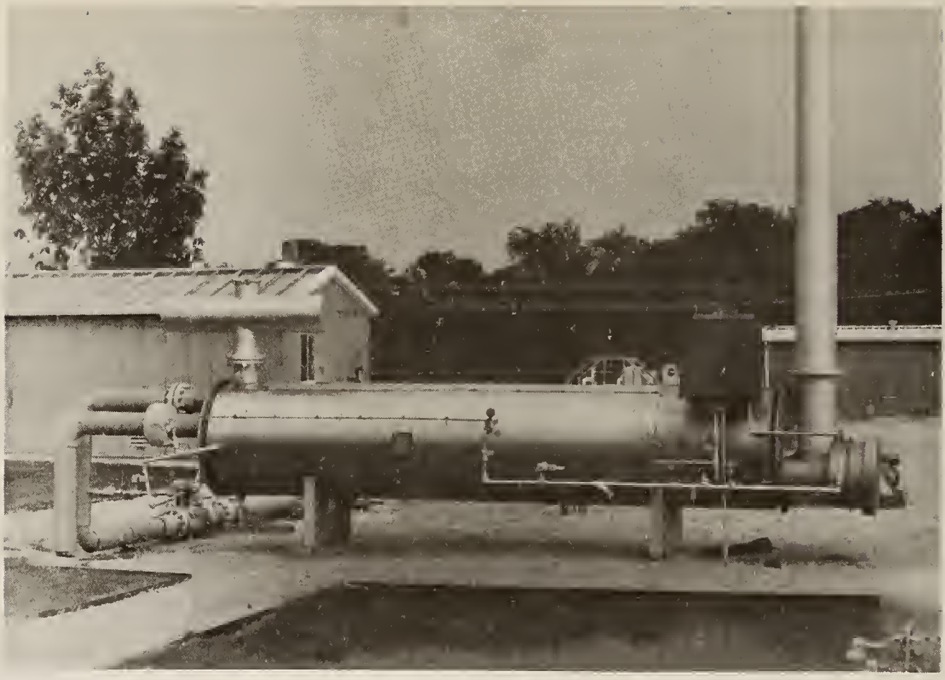


Photo No. 1 (1984-85 Configuration)

Inlet line heater to preheat flowing gas stream above any danger of hydrocarbon liquid dropout in the sonic nozzle throat

Photo No. 2 (1985 Piping Configuration)

Two room instrument building with six inch API meter run in foreground. The four nozzle manifold is behind the building

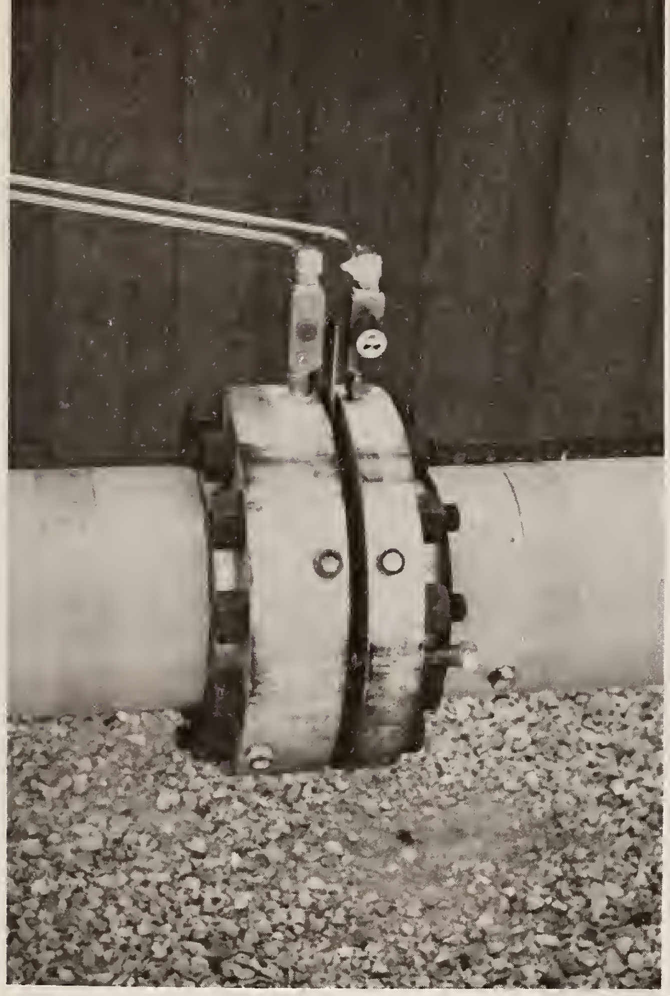


Photo No. 3 (1984-85 Configuration)

Six inch orifice flange

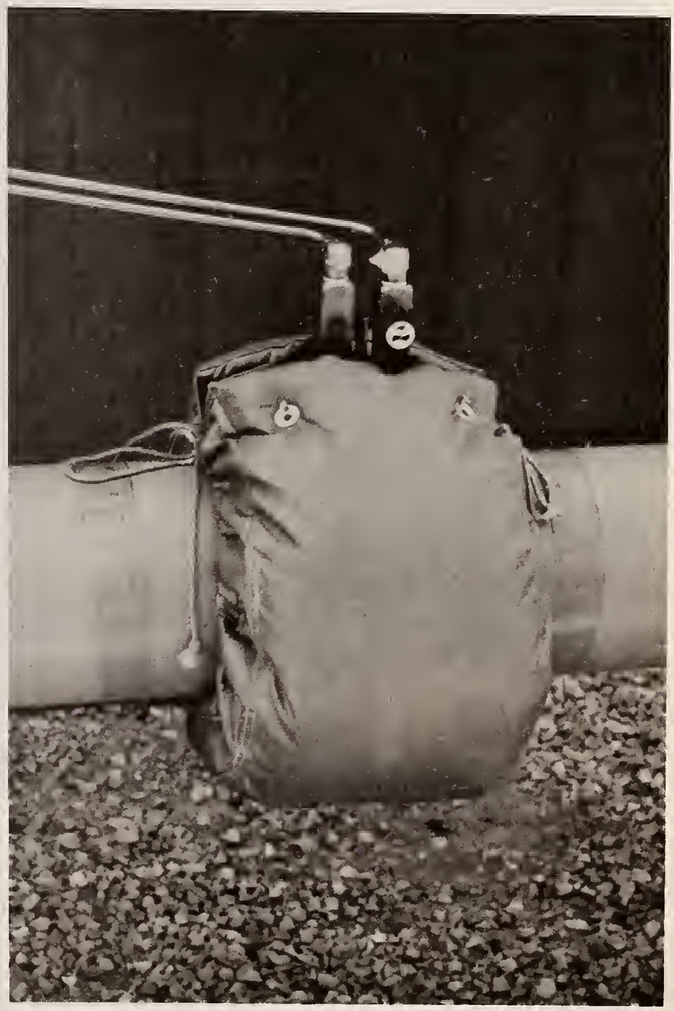


Photo No. 4 (1984-85 Configuration)

Six inch orifice flange with insulation jacket. Entire exposed test loop piping is insulated to reduce ambient temperature affect, especially when a cloud passes over.

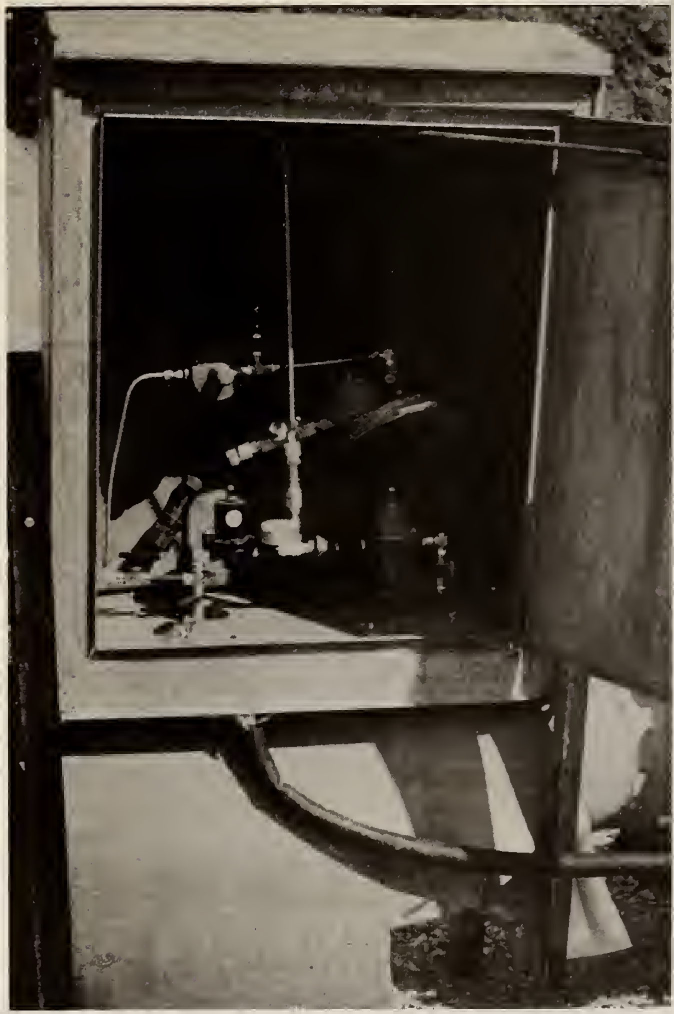


Photo No. 5 (1984-85 Configuration)

Sample probe house with catalytic heater to preheat gas sample for analysis by chromatograph.

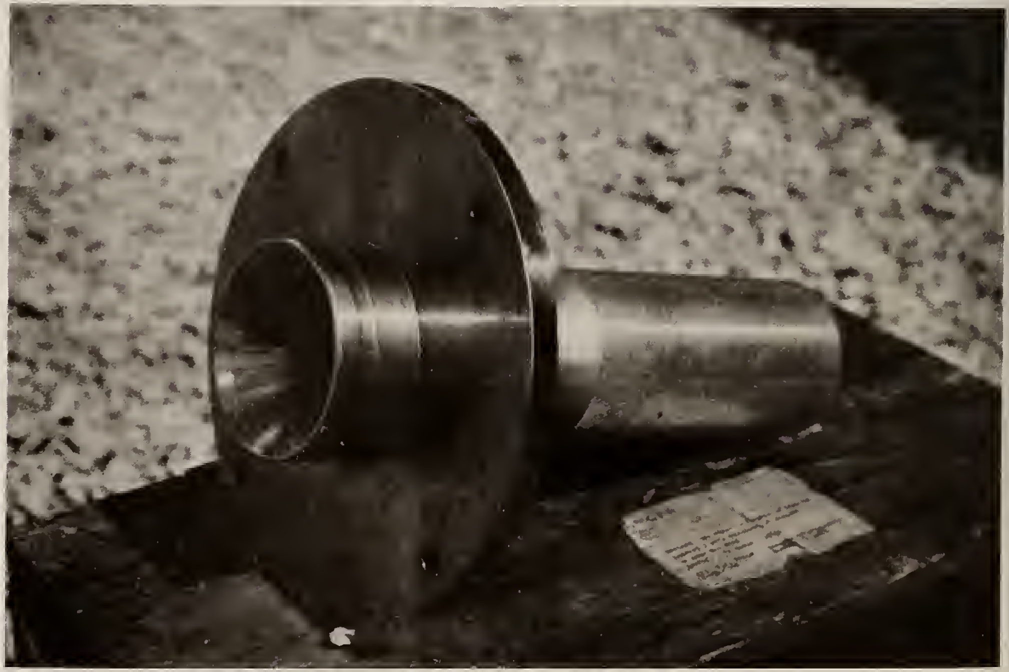


Photo No. 6 (1984-85 Configuration)

Typical sonic venturi nozzle of Smith-Matz design.

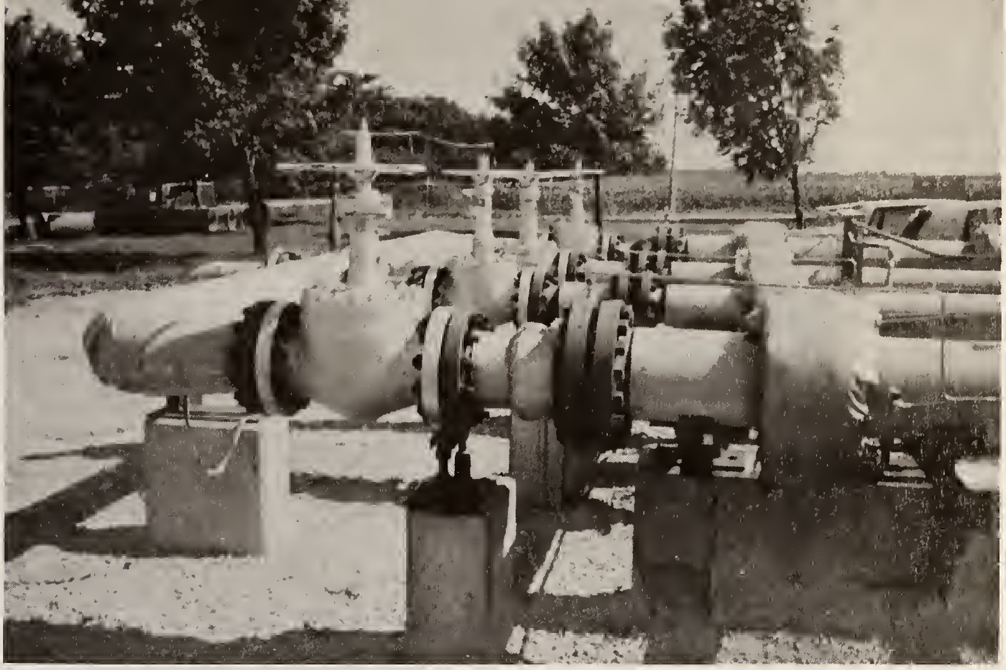


Photo No. 7 (1984-85 Configuration)

View of four block and bleed Orbit valves for large nozzle manifold system.

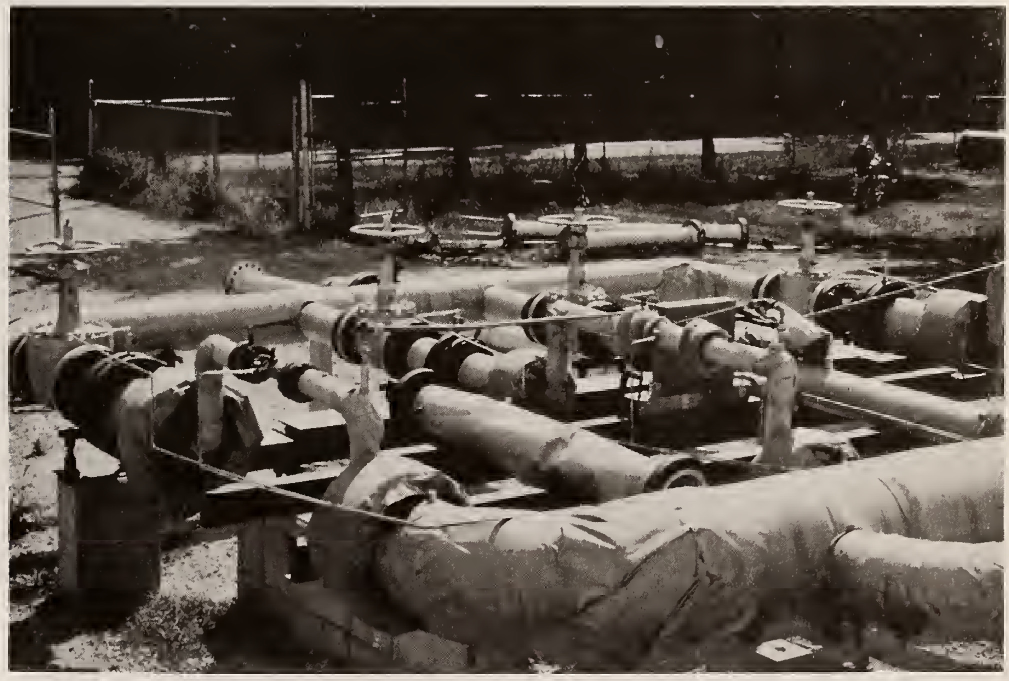


Photo No. 8 (1984 Configuration)

View of four sonix nozzles manifold with two 2-inch nozzle holders and two 6-inch nozzle holders installed.

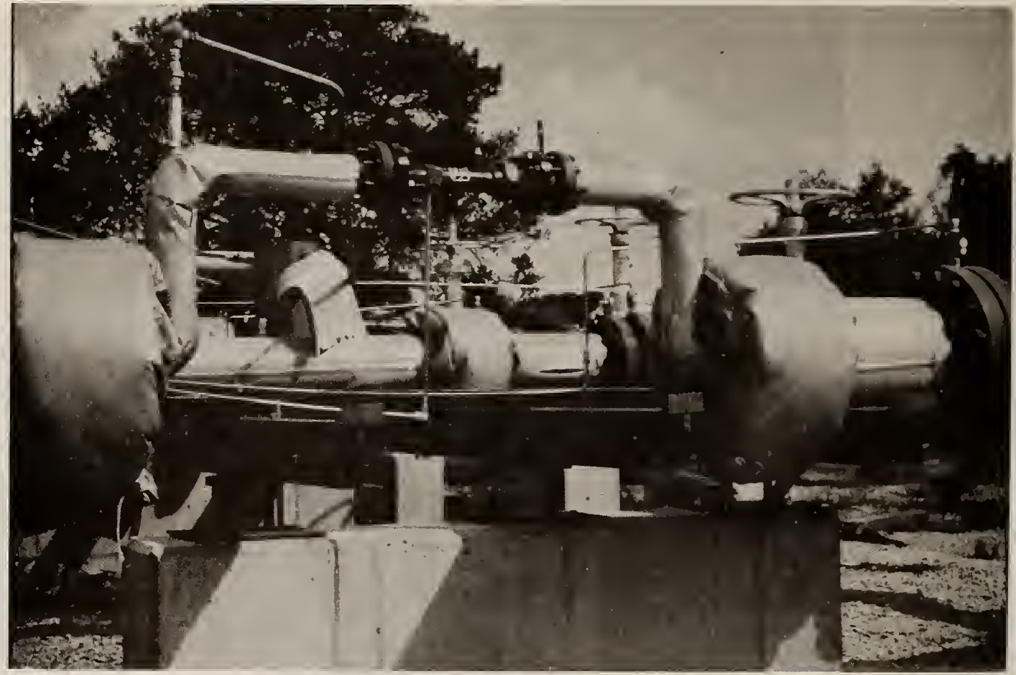


Photo No. 9 (1984 Configuration)

2-inch nozzle holder installed in large manifold system.

Photo No. 10 (1984 Piping Configuration)

Sonic nozzle manifold and instrument building, note air conditioners. Air conditioner on right is explosion proof for hazardous area. The building remained the same for both 1984 and 1985.

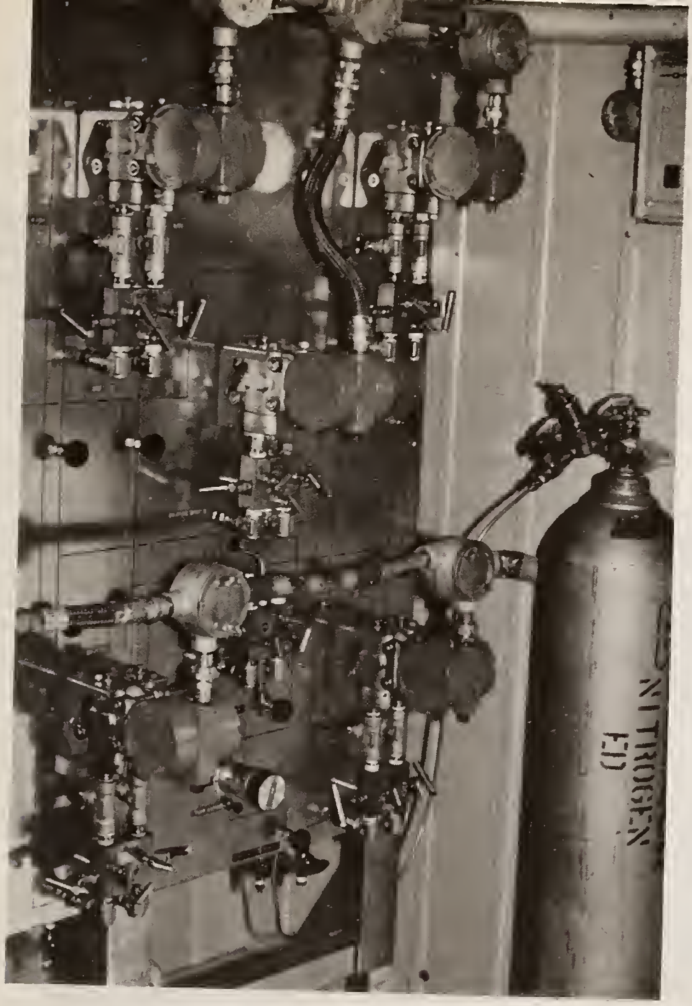


Photo No. 11 (1984-85 Configuration)

Two 0-150 inch differential pressure transducer at top, 400-700 psig static pressure transducer in center, and 0-30 inch transducers on bottom all for the orifice meter. The 0-150 inch and 0-30 inch differential pressure transducers were replaced with 0-200 inch and 0-40 inch transducers for ambient temperature and static pressure effect.

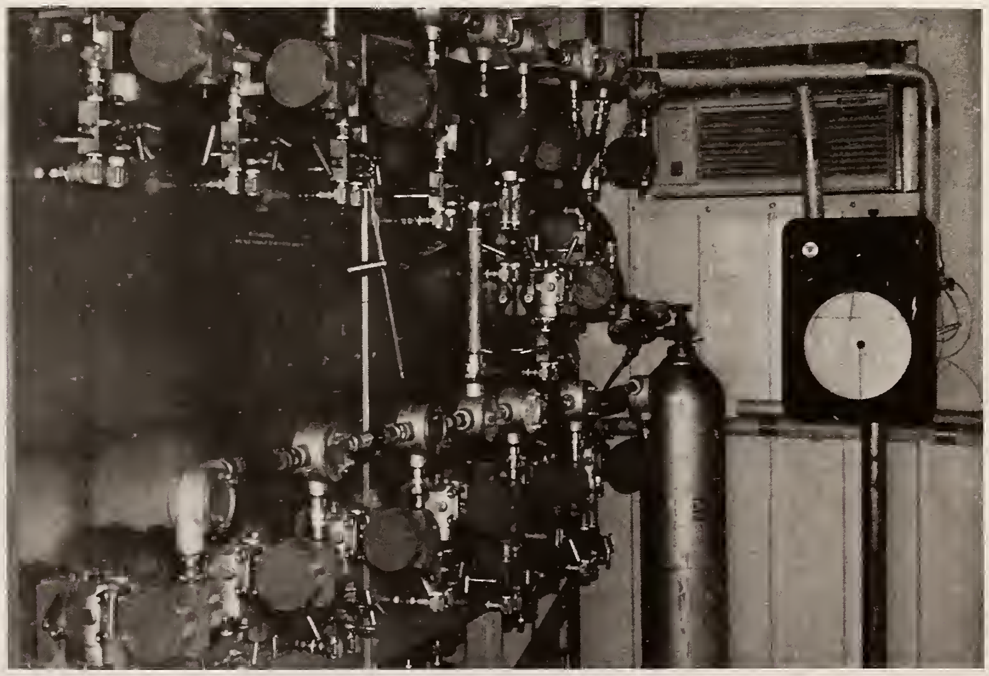


Photo No. 12 (1984-85 Configuration)

Entire transducer board, four static pressure transducers on bottom left are for measuring upstream static pressure for each sonic nozzle. Four static pressure transducers top left measure pressure downstream of each sonic nozzle.

Photo No. 13 (1984-85 Configuration)

Chromatograph standard sample cylinder installed in separate insulated heated enclosure to ensure that no condensation of components occurs.

Photo No. 14 (1984-85 Configuration)

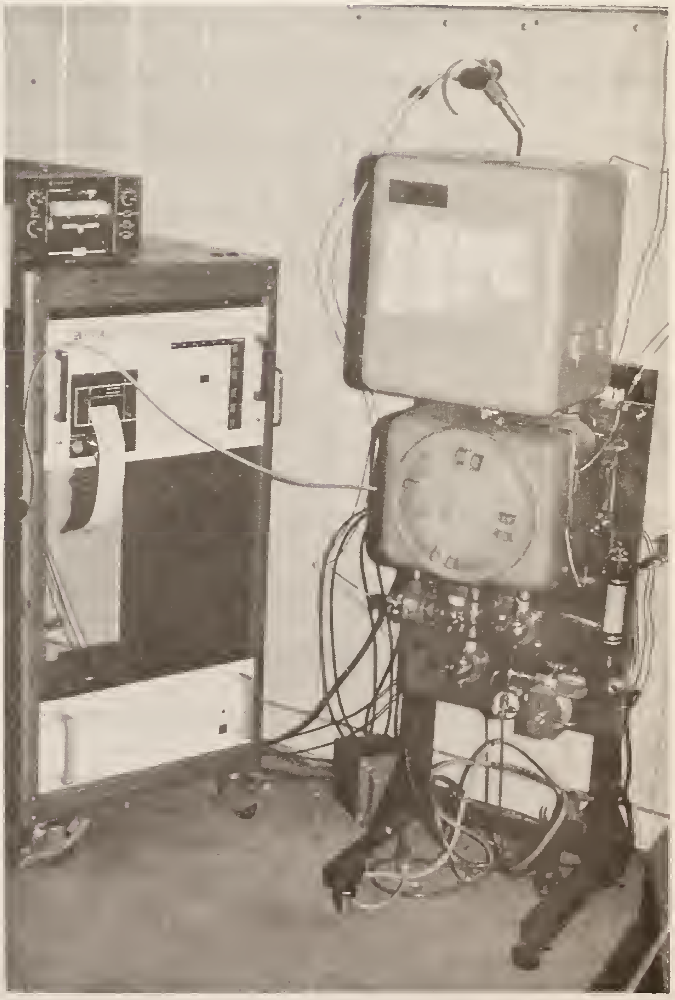
Ametek static pressure dead weight tester with nitrogen bottles to daily calibrate all static pressure transducers.

Photo No. 15 (1984-85 Configuration)

Test loop computer, data is collected from four runs for each flow rate with 150 data points per five minute run.

Photo No. 16 (1984-85 Configuration)

Gas chromatograph a complete gas analysis is made every 13 minutes. Bottom left side is the Ruska DDR 6000 instrument for daily calibration of all the differential pressure transducers.



APPENDIX I

ILLUSTRATIONS AND PHOTOS OF 1985 PIPING AND INSTRUMENTATION REVISIONS

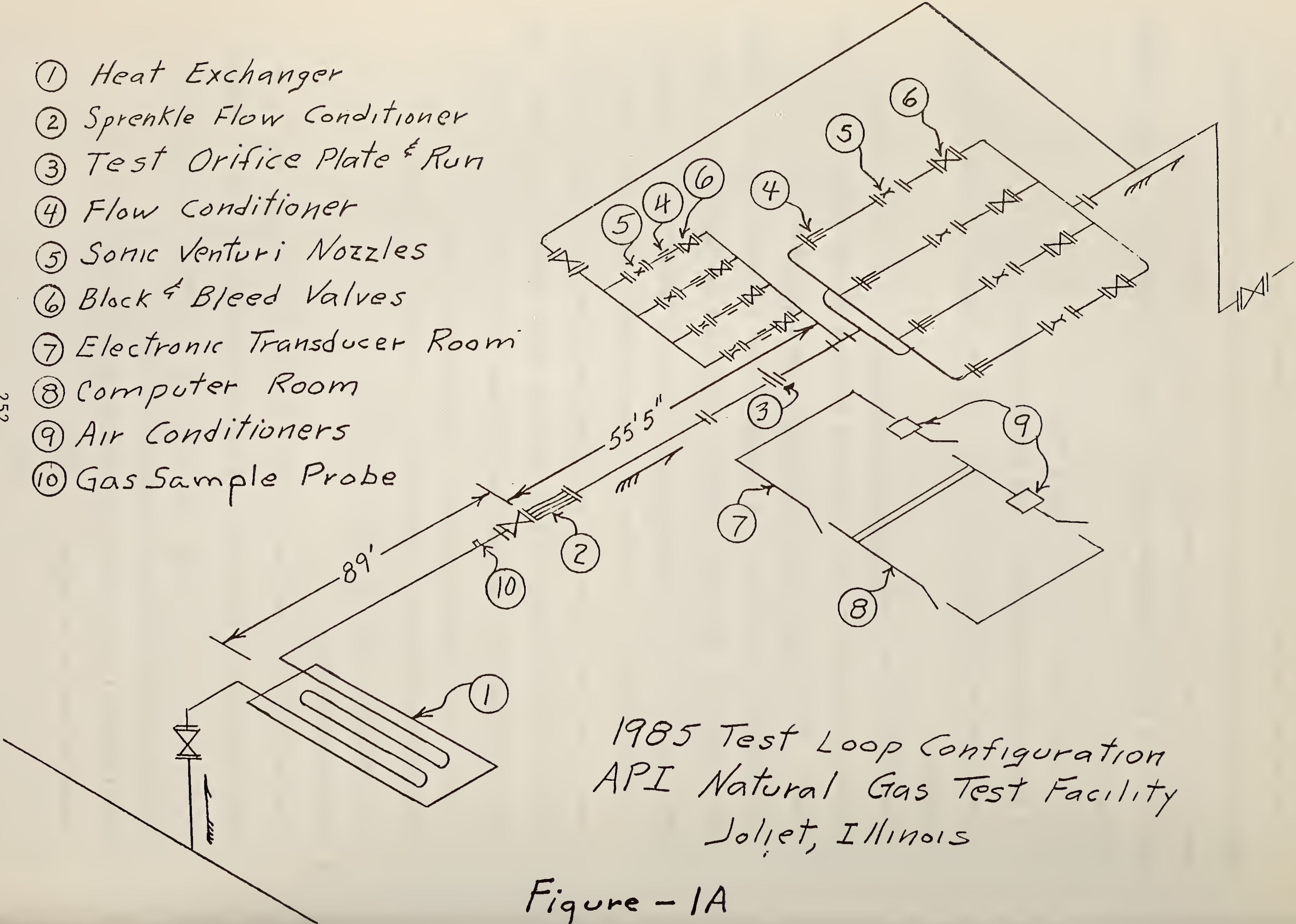
Preliminary review of the 1984 data indicated that a repeat of the gas phase of testing should be done in an attempt to improve the data scatter at low Reynolds number on the lower beta ratio plates. The following modifications to the system were made in order to eliminate or improve certain problem areas:

1. Reference Figure 1-A, 2-A, 7-A, & Photos 17, 18, 19, 20, 21, 22.

   A four nozzle manifold of 2-inch holders for the smaller nozzles was fabricated and installed in parallel with the larger four nozzle manifold system.

   The 1984 computer program utilizing a maximum of four static pressure transducers for four sonic nozzles at one time was not changed. For this reason, of the eight nozzles available, flow rates were limited to any combination of nozzles up to a maximum of four nozzles at one time. Since there were only four static pressure transducers available for the eight nozzles, the static pressure sensing lines were manifolded as illustrated in photo number 22. For example, static pressure sensing line from the #1 run of small nozzle manifold system was manifolded to the static pressure sensing line from the #1 run of the large nozzle manifold system etc. The same system was also utilized for the temperature sensors by physically connecting the temperature sensor for the nozzle in service to the junction box terminal. Temperature sensors not in service were disconnected. Reference photo number 24.
2. Reference Photo 23.

   The two 0-150 inch and two 0-30 inch differential pressure transducers were replaced with two 0-200 inch and two 0-40 inch differential pressure transducers. The new units were internally programmed to compensate for static pressure and ambient temperature effects.
3. All thermo-well type temperature sensors were replaced with direct insertion sensors on October 3, 1985.



① Heat Exchanger
② Sprenkle Flow Conditioner
③ Test Orifice Plate & Run
④ Flow Conditioner
⑤ Sonic Venturi Nozzles
⑥ Block & Bleed Valves
⑦ Electronic Transducer Room
⑧ Computer Room
⑨ Air Conditioners
⑩ Gas Sample Probe

1985 Test Loop Configuration
API Natural Gas Test Facility
Joliet, Illinois

Figure - 1A

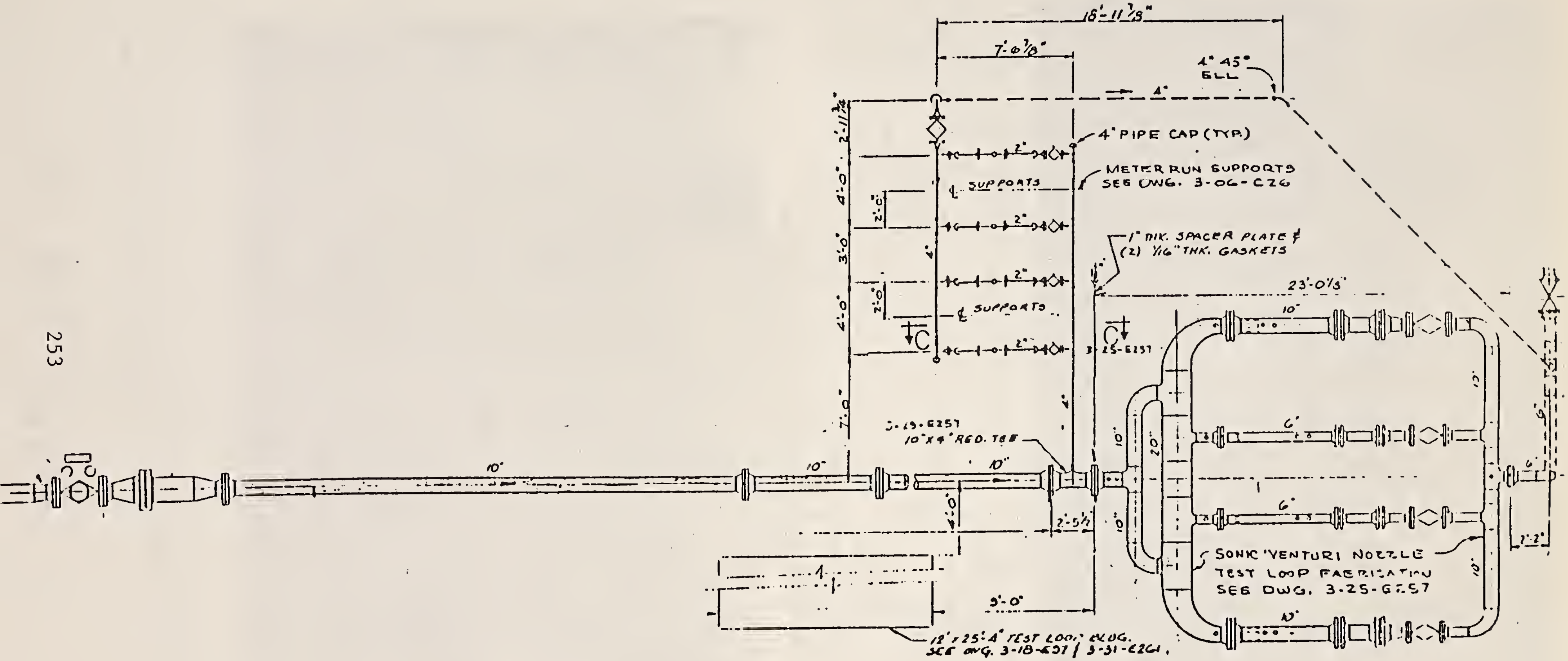
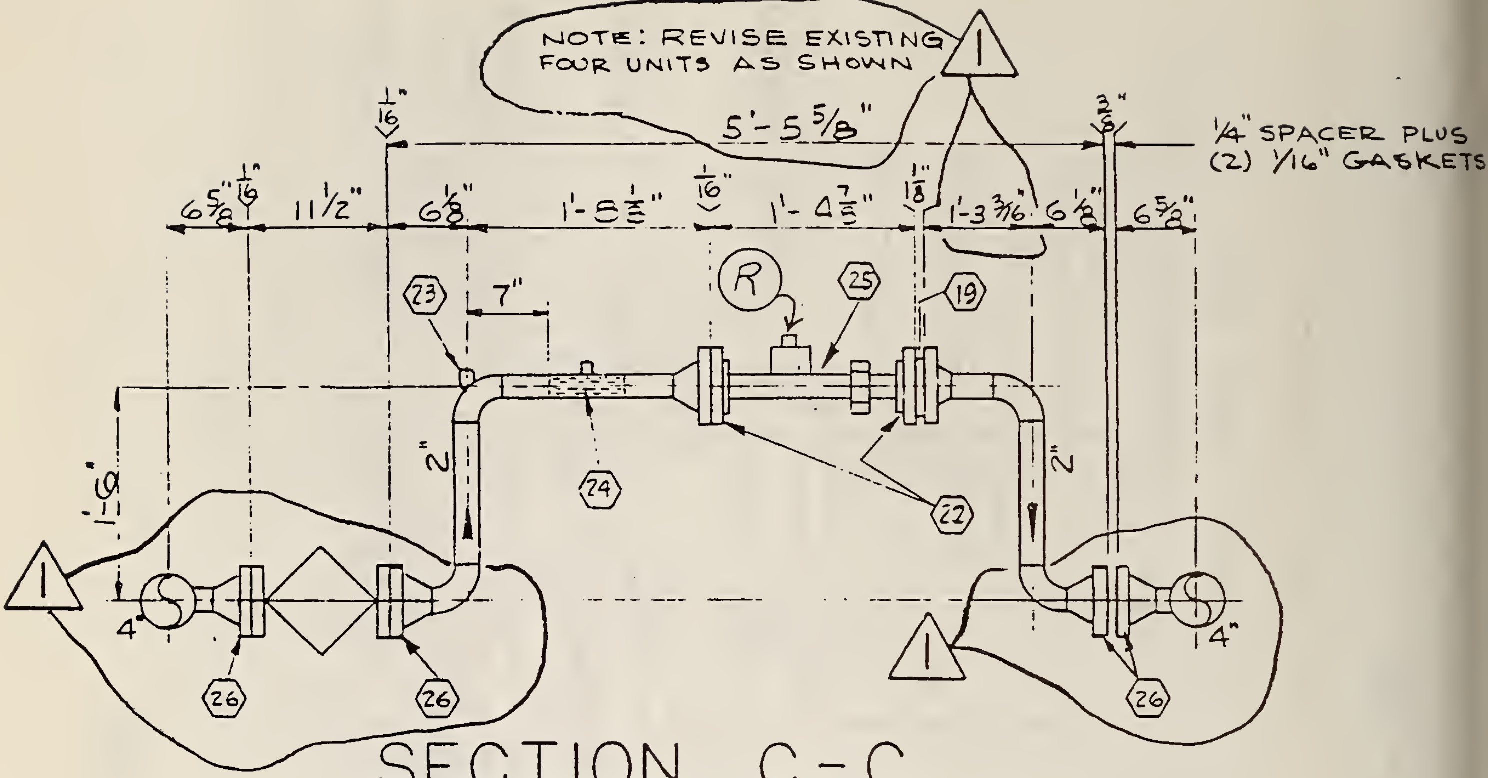

16'-11 7/8"
7'-0 7/8"
4" 45° ELL
4"
4" PIPE CAP (TYP.)
METER RUN SUPPORTS SEE DWG. 3-06-C26
SUPPORTS
2"
2'-0"
2'-11 1/2"
4'-0"
3'-0"
4'-0"
7'-0"
1" THK. SPACER PLATE & (2) 1/16" THK. GASKETS
23'-0 1/8"
C
3-25-E257
10"x4" RED. TEE
10"
6"
20"
2'-5 1/2"
4'-0"
9'-0"
1'-2"
SONIC VENTURI NOZZLE TEST LOOP FABRICATION SEE DWG. 3-25-E257
12' x 25'-4" TEST LOOP ENCLG. SEE DWG. 3-18-E37 / 3-31-E261

Figure 2-A


NOTE: REVISE EXISTING FOUR UNITS AS SHOWN
1
5'-5 5/8"
1/16"
3/8"
1/4" SPACER PLUS (2) 1/16" GASKETS
6 5/8"
1/16"
11 1/2"
6 1/8"
1'-8 1/3"
1/16"
1'-4 7/8"
1/8"
1'-3 3/16"
6 1/8"
6 5/8"
23
7"
R
25
19
2"
24
22
2"
1'-6"
1
4"
26
26
1
26
4"

SECTION C-C

TYPICAL (4) PLACES
(SEE DWG. 3-27-E265)
NO SCALE

20 —

21 —

22 — 2"-600# R.F., F.S., THREADED FLANGE

23 — 3/4" X-HVY. THREADED ELBOLET W/3/4" X-HVY. BULL PLUG

24 — 2" STRAIGHTENING VANES - IN LINE MODEL, CARBON STEEL; DANIEL INDUSTRIES INC. MODEL № 1100L TYPE I, LINE I.D. 1.939" REF. INSTALLATION DETAIL DWG. 03-27-C23

25 — 2" SONIC FLOW NOZZLE & FLOW PROVER HOLDER-SUPPLIED BY API.

△1 — 26 — 2" 600# R.F., F.S. W.N. FLANGE

Figure 7-A

Photo No. 17 (1985 Configuration)

View of eight nozzle manifold system

Photo No. 18 (1985 Configuration)

View of four 2-inch nozzle holders. 2-inch block and bleed valves are upstream of nozzles.

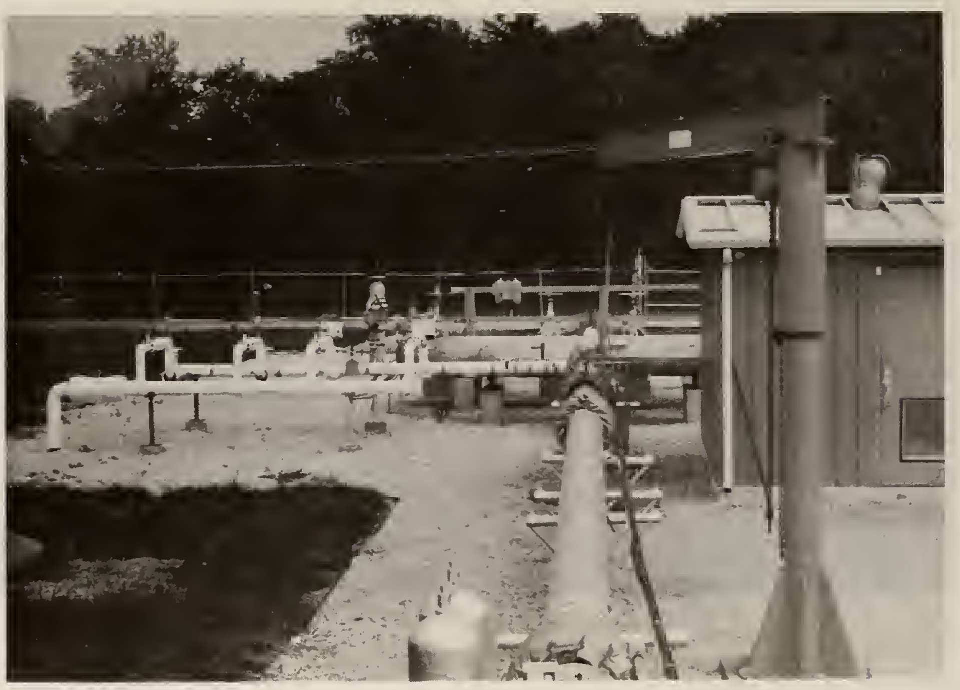


Photo No. 19 (1985 Configuration)

View of 10-inch insulated API meter run and 2-inch nozzle holders

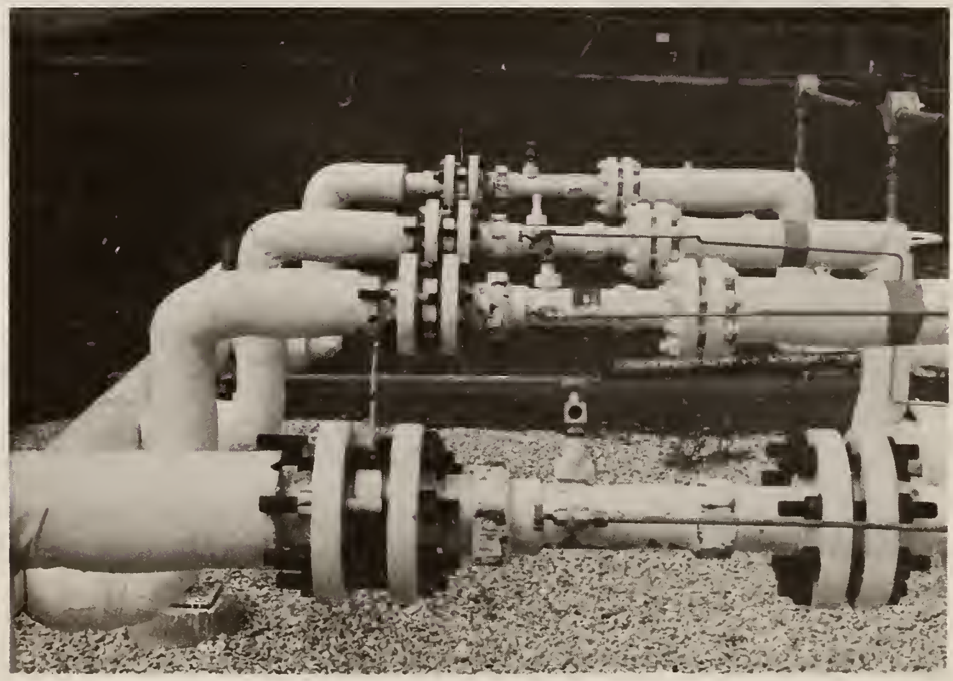


Photo No. 20 (1985 Configuration)

Close up view of 2-inch nozzle holders

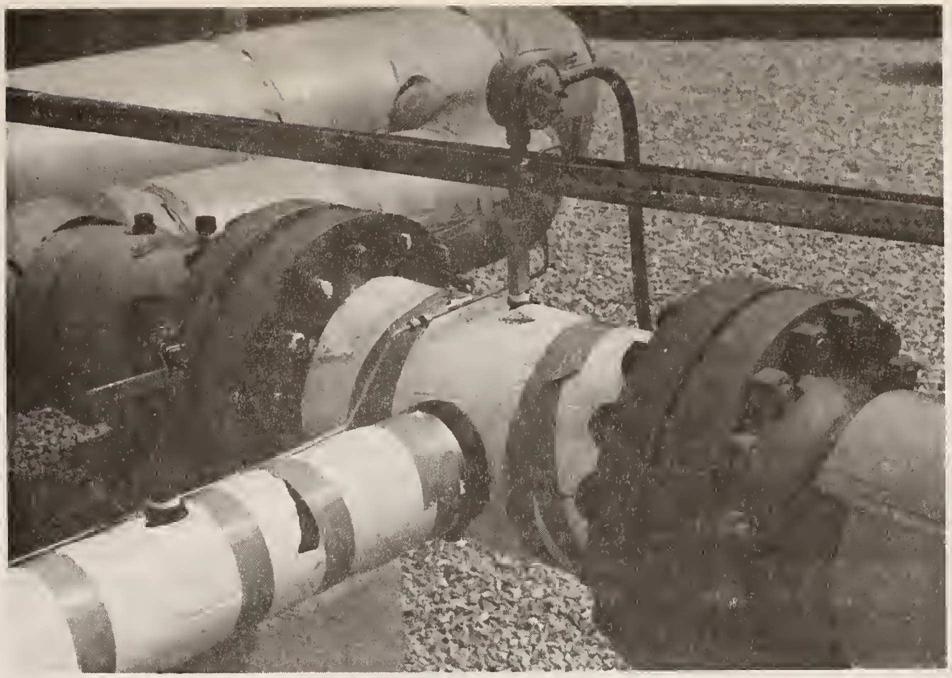


Photo No. 21 (1985 Configuration)

View of 10X10X14" Tee branching off to the 4-inch header for 2-inch nozzle holders. Temperature sensor for the meter run in inserted in the top of Tee. A 10-inch blind is installed between the downstream Tee flanges to isolate the large nozzle holder system from the small nozzles at low flow rates.

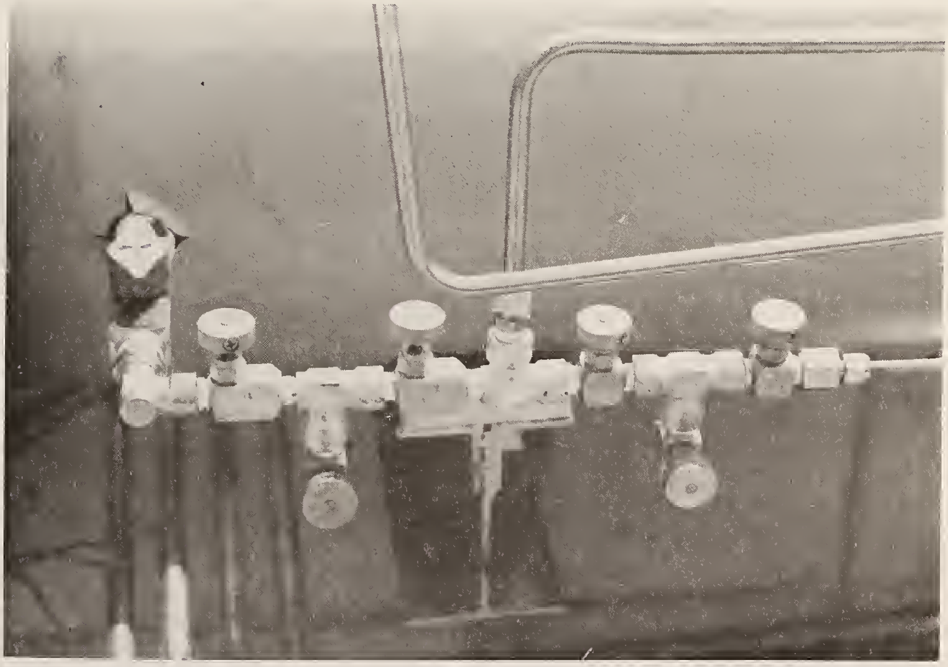


Photo No. 22 (1985 Configuration)

Static pressure sensing line manifold to assure isolation of large nozzle system static pressure from small nozzle system static pressure.

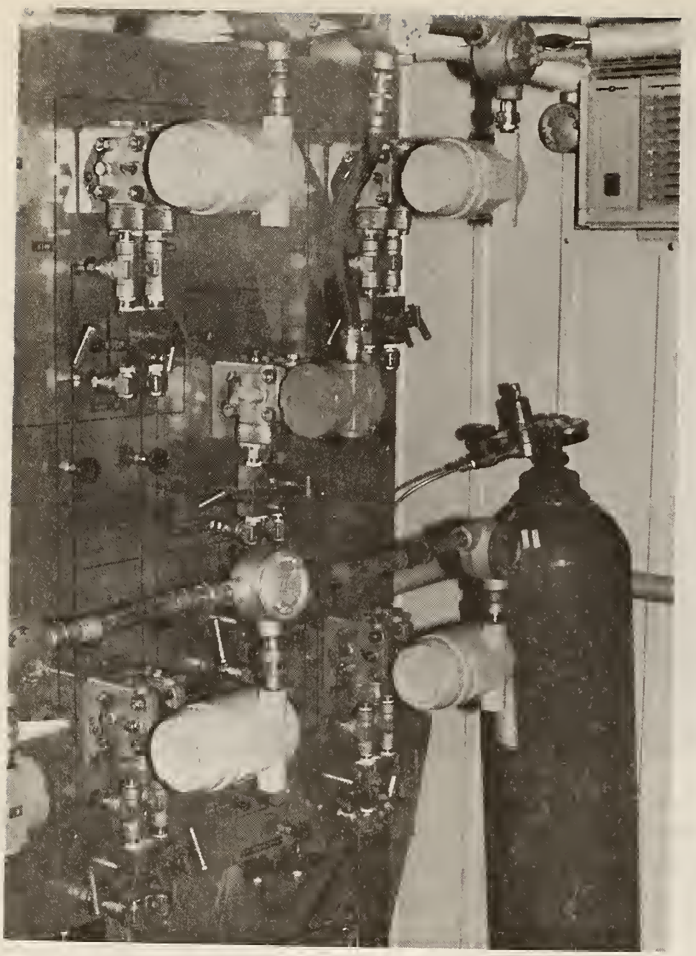


Photo No. 23
(1985 Configuration)

Two 0-200 inch pressure and temperature compensated differentia pressure transducers at top, 400-700 psig static pressure transducer in center, and two 0-40 inch pressure and temperature compensated differential pressure transducers on bottom, all for orifice meter.

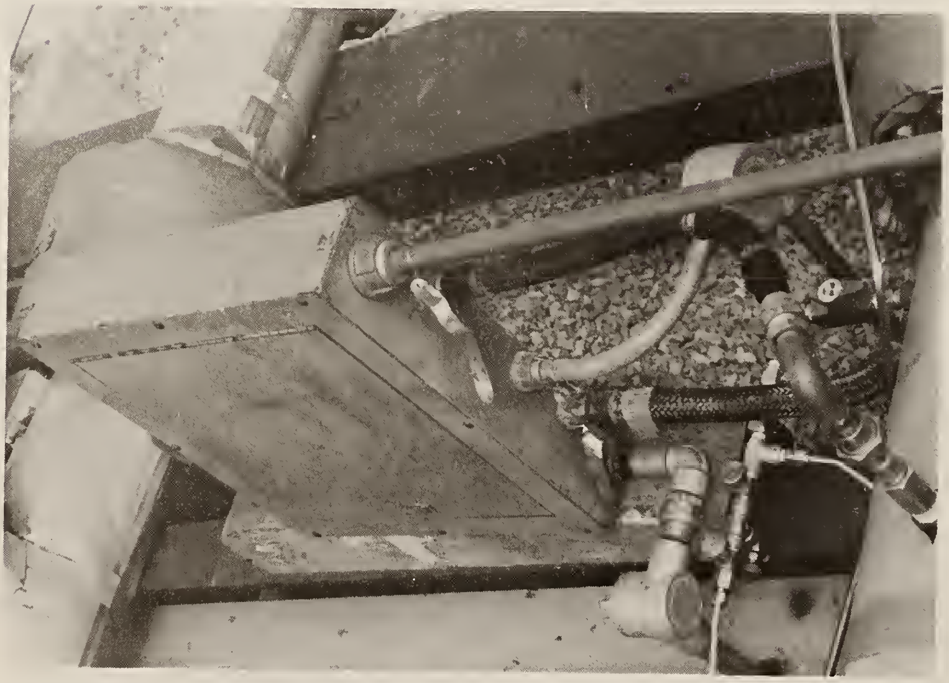


Photo No. 24 (1985 Configuration)

Temperature sensor junction box

APPENDIX B
Operational History of the Project

I. Introduction

This appendix gives a detailed chronological account of the major events which occurred during this project. It is written to provide a record of the progress and significant events which occurred during the project. Significant portions of this appendix were taken from the monthly progress reports prepared for the API by the NBS Principal Investigator (J. Whetstone). These have been edited primarily for clarity in the context of this document and for proper language usage. Verbatim excerpts are usually indented for the sake of clarity. As was mentioned in the introduction of this report, this project was one of three conducted simultaneously by the API between 1982 and 1987. This project was somewhat unique among the three in that responsibility for various portions of the project was split between the National Bureau of Standards (NBS) and the Natural Gas Pipeline Company of America (NGPLA). NBS provided the measurement systems and associated instrumentation and performed the analysis of the data given previously in this report. NGPLA provided the use of its test site located at its Joliet, Illinois Station and was responsible for operation of the tests.

From the outset a strong advisory role was played by the API Program manager and the API's Orifice Meter Database Steering Committee (OSC) which was composed of the following persons:

R. E. Beaty - Committee Chairman,
AMOCO Production Co.
! D. W. Kemp - Cities Service Co.
Occidental Petroleum Corp.
# W. A. Fling - Cities Service Co.
Occidental Petroleum Corp.
* E. L. Upp - Daniel Industries
R. G. Teyssandier - Daniel Industries
H. L. Bean - El Paso Natural Gas. Co., Retired
T. L. Hilburn - Phillips Petroleum
G. G. Less - NGPLA
R. L. Schreibeis - API Staff representation
J. K. Walters - API Staff representation

! D. W. Kemp - ex officio membership on the committee as Chairman, API, Committee on Petroleum Measurement

# API Program Manager

* R. Teyssandier replaced E. L. Upp at approximately the mid-point of the work.

The membership of this committee stayed essentially the same throughout the course of the project. Frequent meetings of this committee occurred and, at times, strongly influenced the course of the planning and execution of the project's technical direction. No major change in the work was made without consultation and agreement of the committee.

The initial plans for the project called for a single testing period to occur during the summer and early fall of 1984. However, events occurring in the intermediate Reynolds number project influenced the high Reynolds number project and a second season of tests were completed in 1985. These tests were run only during warm weather at the test site to minimize or eliminate the possibility of condensation of some of the heavier hydrocarbon fractions in the natural gas.

II. Development and Commissioning of Measurement Systems

Initial planning discussions concerning the type of instrumentation and standards to be used in the measurement systems were held in 1982 and early 1983 in conjunction with reviews of the work then in progress on the intermediate Reynolds number project [B1]. The general philosophy and approach taken in the intermediate Reynolds number project was followed in planning the measurement systems. Particularly, the use of working standards which were closely tied to U. S. national standards was emphasized. This was particularly true for the pressure measurements. Both absolute and differential pressure working standards were planned since the transducers used for these measurements were of industrial quality and it was not clear at the outset at what level of temporal stability these would perform. Additionally, laboratory grade transducers having the required explosion-proof housings and construction were not readily available. Therefore, a double level of redundancy in the differential pressure transducers, and the capability to calibrate both differential and absolute pressure transducers was planned for the instrumentation system. The specifications for the various transducers (pressure and temperature), data logging, and data acquisition and storage computer were completed in early 1983 and were assembled and tested at the NBS-Boulder laboratories by early 1984.

These systems were installed at Joliet in late May of 1984 in preparation for testing to begin in June. During the course of the installation of the systems, the NGPLA personnel responsible for operation of the test were trained in the operation of the data acquisition equipment and familiarized with the various procedures required of the operator by the data acquisition computer software.

III. 1984 Data Collection Season

The 1984 data collection season began in early July with test runs on the FE-7ABC meter tube using both sets of orifice plates. A preliminary review of the results of the tests taken in July and early August showed inconsistent values for the high and low range differential pressure transducer means and the discharge coefficients derived from them for some, but not all of the test runs. Additionally, this inconsistency was intermittent.

A. Investigation of Intermittently Inconsistent Differential Pressure Measurements

An investigation of possible causes for this situation was made by NGPLA operating staff, the NBS principal investigator (J. Whetstone) and Mr. Upp as representative of the OSC. This investigation was performed on August 21 through 23. Its results were given in a report to the full OSC shortly thereafter. The following description is excerpted from that report and has been edited for clarity.

> August 21 - 3:00 to 9:30 PM
>
> The pressure values obtained from the 20-inch and the 200-inch differential pressure transducers in their range of overlap, i.e., 30-40 inches of water, were not in good agreement. Using the computer software (scan program), the pressure values could be observed. Tests of the the computer software were made. By the end of the day it was clear that the software was operating properly. Certain modifications to the transducer calibration program were made to allow a 20-point calibration of each set of transducers. Also it was observed that the pressure lines connecting the RUSKA DDR-6000 to the transducer manifold were not insulated and that in the transducer room these were in the direct air stream from the air conditioner. The air conditioner was turned off and the doors were opened. Subsequent calibration operations proceeded more quickly because the time necessary for the pressure to stabilize at each calibration point was considerably reduced. This was particularly true in the pressurizing stage of the procedure.
>
> August 22
>
> The differential pressure transducers were calibrated at 270 and at 600 psig. These two calibration passes agreed with one another rather well. After completing the calibration procedures the scan program was entered, and the differential pressure values at zero differential pressure conditions were displayed on the console screen. These values are updated on the screen every 10 seconds and agreed within .05 inches of water of each other. The transducers were then cycled to atmospheric pressure and to 600 psi and to 271 psi. During these operations the transducers were exposed to large pressure differentials. After one of these excursions the values of the zero differential pressure values computed for the 200-inch transducers differed from those of the 20-inch transducers by as much as 0.5 inches of water. The values of the two 20-inch transducers

during these operations were always within 0.1 inch of water or less of zero. The zero differential pressure values for the 200-inch transducers were continually changing with each pressurization step.

The pressure was set to 600 psi and the calibration pump was used to pressurize the transducer manifold to various levels up to approximately 200 inches of water differential. After each of these cycles the zero differential pressure values for the 200-inch transducers changed while the 20-inch transducers remained at their previous values, very near zero. During this entire operation the scan program was running, using the coefficients obtained from the last 600-psi calibration done between 2:30 and 3:30, i.e., nothing was done to the computer or to its software.

The scan program was left running over night. The values displayed are given below for various times. DP1 and DP2 are the 20-inch transducers. The pressure units are inches of water.

DATE/TIME	DP1	DP2	DP3	DP4
8/22 5:45	-0.01	0.02	-0.13	-0.15
9:23	-0.04	0.02	0.30	0.36
8/23 7:28	-0.06	0.01	0.49	0.58

August 23

The differential pressure transducer procedure was modified for a 20-point calibration to give a larger number of observation points to check whether the quadratic calibration equation was causing a problem. This calibration was completed and the scan program was entered. It used the coefficient values gotten from the 20 calibrations.

Time	DP1	DP2	DP3	DP4
10:50	0.02	0.04	0.04	0.01

Put a differential of 100 inches on the transducers.

0.01	0.03	-0.04	-0.08

Repeat the pressure cycle

0.02	0.03	-0.03	-0.05

The pressurizing pump was used to set several differential pressure values in the overlap zone of the transducers. The pump was then valved off. The following were recorded from the scan program.

4.86	4.86	4.80	4.78
9.72	9.69	9.65	9.61
19.86	19.82	19.79	19.77
35.12	35.12	35.04	35.00

The transducer manifold was pressurized to 100 inches of water and a similar schedule was run.

36.79	36.82	36.77	36.74
30.90	30.89	30.86	30.84
5.75	5.74	5.70	5.66

(The following is a record of the section of the notebook recorded in my absence by E.L. Upp.) Shut down to go to 100 inches then back to zero to check the method of bleed down. The pump is backed off before the bypass is opened. The 200-inch goes to negative diff. press. of 38 inches and zero shows a great shift, however if the bypass is opened before the pump is backed off the zero's agree and diff. press. agree to 35 inches on all four transducers. See data below.

9.91	9.89	9.85	9.81
16.73	16.68	16.66	16.62
23.14	23.09	23.07	23.04
30.69	30.66	30.59	30.57
35.30	35.30	35.20	35.17
28.94	28.91	28.84	28.82
19.37	19.32	19.29	19.25
8.72	8.70	8.65	8.60
.02	.04	-0.03	-0.07

The transducer manifold was valved off the nitrogen bottle supply used in calibration procedures and in the tests described above, and on to the orifice plate taps with no flow in the line. The line pressure was approximately 700 psi. By manipulating the crossover valves and changing to a pressure of 700 psi the zero differential pressure values displayed on the screen were the following.

Time	DP1	DP2	DP3	DP4
	0.00	0.04	0.35	0.33

The transducer manifold was valved back to the nitrogen bottle with no change resulting in the zero differential pressure values.

During the operations described above the supposition was put forth that the large shifts in the 200-inch zero values were caused by allowing the transducers to experience large negative differential pressures. To test this the following tests were performed and data taken.

Time	DP1	DP2	DP3	DP4
12:00	0.01	0.04	0.36	0.32

Put a small negative differential pressure on the manifold and return to crossed over condition.

0.01 0.04 0.35 0.32

Go to +50 inches diff. press. and return with at least a -1.5 in. of water excursion shown on the screen during the operation.

0.01 0.04 0.35 0.32

Repeat but go to +200 in. diff. press. A larger negative swing was observed when returning.

0.01 0.04 0.28 0.23

Repeat to +150 in. water with a -36 in. displayed on the negative swing.

12:19 0.01 0.03 0.25 0.21

Go to Lunch with the same values as at 12:19 displayed at 1:50

Conclusions Drawn From These Data

The 200-inch transducers are affected by pressure excursions which bring them against their mechanical stops. Especially influential are negative excursions. The magnitude of the shifts in the response of the 200-inch transducers can be as large as plus or minus 0.5 inches of water. The 20-inch transducers are much more stable, especially DP2.

Subsequent Actions and Recommendations

1. The 200-inch transducers should be replaced by 150-inch transducers taken to Joliet by E. L. Upp the previous week.

2. E. L. Upp and W. A. Fling would assess the data to determine which test points and orifice plates should be rerun.

3. A change in procedures and/or a modification in equipment should be effected to minimize or eliminate negative excursions of the differential pressure transducers.

After a discussion with Jim Jones, NGPLA Joliet Station Superintendent, Dr. Whetstone decided to reduce the number of test points taken at each flow rate from six to four. This corresponds to two 13-minute cycles of the Encal chromatograph rather than three. The reduction in the quantity of data at each flow rate setting should not adversely affect the quality of the database while increasing the number of plates which can be tested in a day.

Following discussions of the situation with the OSC, two 150-inch of water transducers were installed the last week of August. During the week of September 7, 1984 several transducer calibration passes were made with the result that one of the new 150-inch transducers appeared to be performing approximately 10 times worse than the other, i.e., one had a residual standard deviation for the fit of 0.001 psi while the other had a residual standard deviation of approximately 0.014 psi. Analysis of the calibration data and the fitting procedure showed that the quadratic model used was not properly representing the response of the second transducer. The model used to fit the calibration data was modified to a cubic. This change reduced the second transducer's residual standard deviation value to a level equivalent to that of the first. A cubic model was used for both of the transducers.

The calibration procedures were modified somewhat to reduce the possibility of large differential pressure excursions by setting the static pressure at which the procedures were performed to a value very near the operating pressure of the pipeline.

Following these changes the testing program was resumed. The OSC had decided to repeat all of the tests on the orifice plates run previously. To clearly mark the break in the data collected, the test run number used to begin this block of tests was set at 501 which was the first test performed on September 10, 1984. Subsequent test runs were numbered sequentially ending with test run 970 taken on November 11, 1984.

IV. The 1985 Data Collection Season

Events occurring in the companion Intermediate Reynolds Number Project [B1] during the winter and spring of 1985 relating to corrosion-induced, surface-roughness effects on discharge coefficient measurements and a desire to repeat certain of the test runs taken the previous year caused the OSC to decide to extend the project. Differential pressure transducers, which were thought to have better operating characteristics, were available, and repetition of certain of the test runs performed in the cooler part of the testing season could be re-tested at a time when the pipeline gas was warmer.

Test Loop Modifications

Additionally, a second nozzle manifold was fabricated and installed to substantially eliminate the need to depressurize the pipeline to change nozzles. The second manifold allowed all but one of the nozzles to be mounted in the test loop. This manifold was 2-inches in diameter and held four of the five small nozzles allowing a broader range of flows to be achieved without physically changing nozzles with the attendant test loop pressure cycling. A requirement of the instrumentation associated with the new manifold was that it should be configured and operating procedures modified such that no changes in the data acquisition, analysis and storage software was necessary. The two manifolds were fitted with pressure tap line valves so that the transducers measuring the nozzle plenum pressures could be paired, thereby maintaining the use of four pressure transducers. The pressure transducers on the downstream side of the nozzles were not paired. Therefore, when the small nozzles were in operation the downstream pressures were not measured, and the recorded values were those of the larger nozzles which were not operational and were generally at substantially lower pressures.

Thermometers were installed in the small nozzles. This increased the set of thermometers in potential use to nine. Operating procedures were changed so that the operators physically switched the various thermometer leads to the four ports of the data logger. A pair of PRT's were assigned to each data logger port in correspondence with the pairing of the nozzle static pressure transducers.

The new differential pressure transducers and the nozzle manifold were installed and operational checks were completed July 23, 1985. Test run number 1 was taken July 24, 1985. Data collection activities ran smoothly with no major difficulties in operations. A new NGPLA operator had been assigned to the project for the 1985 season which resulted in the expected changes in some details of the operation, but no significant difficulties were identified in the operating procedures.

The initial meter tube tested in the 1985 testing season was the FE-9ABC meter tube using 10 of the orifice plates of the A and B sets. These tests were completed in early September. The second meter tube to be tested was FE-7ABC which had been run the previous summer and fall. The test run data was taken for most of the plates in early October. The scatter in data taken in 1984 and 1985 indicated that a systematic effect may be present. To investigate the possibility of malfunctions in the instrumentation and computer systems, a group of tests was made jointly by NBS and personnel from Colorado Engineering Experiment Station, Inc. The following is the report of those diagnostic tests. It has been edited for clarity here, but is given without essential deletions. Editorial comments or adjustments are enclosed in brackets {}. To be specific concerning the equipment in use, manufacturer's names and model numbers are given in this report. In doing so the National Bureau of Standards in no way explicitly or implicitly recommends or endorses any such devices or instruments [B2].

NBS/CEESI Diagnostic Test

Summary Report
of
Joliet Test Loop Instrumentation System Investigation

performed by

C. L. Britton - CEESI
S. H. Caldwell - CEESI
W. G. Cleveland - NBS
J. R. Whetstone - NBS

During October 14 through 18, 1985

submitted

October 25, 1985

This summary report describes tests of the instrumentation system installed at the Natural Gas Pipe Line Company of America's Joliet, Ill. test loop as part of the API sponsored Orifice Database Project. Colorado Engineering Experiment Station. Inc. (CEESI) and National Bureau of Standards personnel performed these tests. The purpose of this investigation was to determine whether the source of the scatter in the data collected during 1985 at Joliet could be isolated, and, if so, what measures could be implemented to reduce the variation in the data.

I. Auxiliary Equipment

Messrs. Britton and Caldwell brought several pieces of auxiliary equipment to be used to check the operation of the currently installed instrumentation system. This included measurements of temperatures other than those currently logged by the instrumentation system. The auxiliary equipment used were the following.

1. Hewlett Packard Model 7090A Measurement Plotting System,
2. Fluke Model 2190A Digital Thermometer,
3. Fluke Model 2300A Scanner,
4. Fluke Model 8520A Digital Multimeter,
5. Mensor 0 - 2500 psid Digital Pressure Transducers (2),
6. Ametek Model PK-300 Deadweight Tester, and
7. Honeywell Differential Pressure Transducer Model STD120-3000.

The Honeywell transducer was installed with approximately 2 feet of stainless tubing between it and the pressure taps of the 6-inch orifice meter, FE-7ABC. It had been calibrated during the week of October 7, 1985 at CEESI. Due to the restraints of the piping system, CEESI's Honeywell transducer was not calibrated after installation in the system. (The hand Pump used to pressurize the differential pressure transducer piping circuit for calibration was not large enough to handle the added volume.) This transducer was connected in parallel with the four Honeywell differential pressure transducers of the instrumentation system.

One of the Mensor transducers monitored the downstream tap of the orifice plate and was connected to the piping system at the Rosemount static pressure transducer. The second Mensor transducer monitored the inlet pressure of Nozzle Run D in the 2-inch manifold and was connected at the corresponding Rosemount transducer on the instrument panel.

The Fluke digital thermometer was installed with four thermocouple probes. The locations of these probes were the following.

1. In the water bath of the gas fired heater located upstream of the orifice meter
2. On the outer surface of the orifice meter near the orifice flange.
3. Upstream of the orifice, in the gas stream. The penetration into the gas stream was made approximately 50 feet from the orifice meter flange.
4. Downstream of the orifice plate, in the gas stream, located approximately six inches from the bare platinum resistance thermometer of the instrumentation system and used for recording the temperature at the orifice.

The Fluke scanner was used to sequentially display the temperature values from each of the probes on the digital thermometer.

The HP Model 7090A was used for recording and plotting the voltage values from various transducers, typically the differential pressure transducer brought by CEESI and one of those of the instrumentation system. The orifice static pressure transducer's voltage was monitored by the third channel of the 7090A. This connection was made at the transducer housing.

In addition a Daniel Industries Square Root Error Indicator Model 50 owned by NGPLA was installed in parallel with {the} CEESI Honeywell differential pressure transducer. The instrument failed to power up and consequently, was not used.

II. Description of Tests and Observations

1. Observation of the Differential Pressure Transducer Calibration Procedures

Initially a calibration pass of the 40-inch differential pressure transducers was made. This was followed immediately by a second pass to determine the level of difference between two calibration passes closely spaced in time. Tables 1A and 1B list the effects of successive calibration passes for one transducer of each span setting, i.e., 40 and 250

Table 1A. Effects of calibrations over a three week period on Honeywell differential pressure transducer HW-003

Date	Run No.	Cal. Pass	Transducer Response Coefficients			
			A_0	A_1	A_2	A_3
9/26/85	449	-	-0.361166	0.180806	-	-
10/08/85	529	-	-0.361730	0.180901	-	-
10/15/85	-	1	-0.361639	0.181020	-	-
10/15/85	-	2	-0.361554	0.180953	-	-
10/15/85	541	3	-0.361389	0.180904	-	-
10/16/85	557	-	-0.359589	0.180583	-	-
10/17/85	563	-	-0.361642	0.180889	-	-

Date	Run No.	Cal. Pass	Calculated Diff. Pressure at 4 and 8 Volts in In. of Water			
			DP @ 4V	Diff.	DP @ 8V	Diff.
9/26/85	449	-	10.032	-	30.070	-
10/08/85	529	-	10.027	-0.005	30.076	0.006
10/15/85	-	1	10.042	0.010	30.105	0.035
10/15/85	-	2	10.037	0.005	30.092	0.022
10/15/85	541	3	10.036	0.004	30.086	0.016
10/16/85	557	-	10.051	0.019	30.065	-0.005
10/17/85	563	-	10.028	-0.004	30.076	0.006

Table 1B. Effects of calibrations over a three week period on Honeywell differential pressure transducer HW-002

Date	Run No.	Cal. Pass	Transducer Response Coefficients			
			A_0	A_1	A_2	A_3
9/26/85	449	-	-2.24822	1.12409	0.00052559	-0.00001533
10/08/85	529	-	-2.25591	1.12826	0.00061120	-0.00000309
10/15/85	-	2	-2.25335	1.12629	0.00051617	-0.00003056
10/15/85	541	3	-2.25694	1.12948	-0.00015505	0.00001111
10/16/85	557	-	-2.24615	1.12342	0.00093670	-0.00004363
10/17/85	563	-	-2.26037	1.13196	-0.00044275	0.00002334

Date	Run No.	Cal. Pass	Calculated Diff. Pressure at 4 and 8 Volts in In. of Water			
			DP @ 4V	Diff.	DP @ 8V	Diff.
9/26/85	449	-	62.496	-	187.588	-
10/08/85	529	-	62.561	0.065	187.650	0.062
10/15/85	-	2	62.567	0.071	187.701	0.113
10/15/85	541	3	62.597	0.095	187.710	0.122
10/16/85	557	-	62.612	0.116	187.825	0.237
10/17/85	563	-	62.671	0.175	187.828	0.240

inches of water. {Both transducers demonstrated a reproducibility of approximately 0.09 percent or less of the full span of the response over the three week period. Transducer response function polynomial coefficients listed results in pressure units of psi. The conversion factor 27.7076 inches of water at 60 °C/psi was used. Differences are taken between run 449 and the others listed.}

2. Calibration of the Static Pressure Transducers

After calibrating the differential pressure transducers, the static pressure transducers were calibrated. Following the data collection procedures, the microprocessor system fit the transducer responses and rejected these fits based on the previously set limits to the goodness of the fit. CEESI's Mensor transducers were on-line during the period of data collection and agreed within 0.2 psi of the deadweight tester values.

A second calibration pass was initiated and a difference of 2 psi observed at the 400 psi point between the Mensor transducers and the deadweight tester. This difference was not observed at 500 psi. The calibration procedure was aborted due to incorrect input to the computer system. The second static pressure calibration was begun after the deadweight tester had been inspected. During this inspection the ball and ball retaining cylinder were found to be excessively dirty for this type of instrument. These were cleaned and the tester reassembled, and the calibration procedures restarted. Although the ball was not sticking, the mensor transducers were indicating 401 psi with the deadweight tester set for 400 psi. The tester still had something malfunctioning and further inspections were made. It was found that the weight stack was oscillating or chattering. Increasing the pressure to 500 psi decreased the amplitude of the chatter significantly and the mensor transducers indicated 500 psi within approximately 0.2 psi. It was decided to proceed with the static pressure transducer calibration procedures and to observe whether the tester chattered at the succeeding pressures. The tester was not observed to chatter at the higher pressures, but still exhibited chatter at the 400 psi pressure point. Tables 1C and 1D list the effects of successive calibration passes on the static pressure transducers connected to the orifice meter and one nozzle. {Maximum variation relative to test run 449 for both transducers is approximately 1 psi at 775 psig.}

Table 2A. Effects of calibrations over a three week period on Rosemount static pressure transducer S/N 541529 (orifice static pressure)

Date	Run No.	Cal. Pass	Transducer Response Coefficients A_0	A_1	A_2	A_3
9/26/85	449	-	-234.013	127.468	-0.139236	-
10/08/85	529	-	-239.116	128.980	-0.257092	-
10/15/85	-	2	-239.137	129.176	-0.290898	-
10/15/85	541	3	-235.251	127.741	-0.172472	-
10/16/85	557	-	-232.099	127.255	-0.157710	-
10/17/85	563	-	-230.056	126.689	-0.122678	-

Date	Run No.	Cal. Pass	Calculated Static Pressure at 4 and 8 Volts in psia P @ 4V	Diff.	P @ 8V	Diff
9/26/85	449	-	273.63	-	776.82	-
10/08/85	529	-	272.69	-0.94	776.01	-0.81
10/15/85	-	2	272.91	-0.72	775.64	-1.17
10/15/85	541	3	272.95	-0.68	775.64	-1.17
10/16/85	557	-	274.40	0.77	775.85	-0.97
10/17/85	563	-	274.74	1.11	775.60	-0.99

Table 2B. Effects of calibrations over a three week period on Rosemount static pressure transducer S/N 541528 (nozzle static pressure - position 1)

Date	Run No.	Cal. Pass	Transducer Response Coefficients A_0	A_1	A_2	A_3
9/26/85	449	-	-241.874	126.512	-0.0379579	-
10/08/85	529	-	-233.779	124.189	0.115094	-
10/15/85	-	2	-237.940	125.675	-0.0061641	-
10/15/85	541	3	-233.712	124.121	0.119199	-
10/16/85	557	-	-227.491	122.939	0.174872	-
10/17/85	563	-	-227.135	122.746	0.189841	-

Date	Run No.	Cal. Pass	Calculated Diff. Pressure at 4 and 8 Volts in In. of Water P @ 4V	Diff.	P @ 8V	Diff
9/26/85	449	-	263.57	-	767.79	-
10/08/85	529	-	264.82	1.25	767.10	-0.69
10/15/85	-	2	264.66	1.09	767.06	-0.73
10/15/85	541	3	264.68	1.11	766.89	-0.91
10/16/85	557	-	267.06	3.49	766.21	-0.58
10/17/85	563	-	266.89	3.32	766.98	-0.81

3. Comparison of Parallel Connected Instrumentation

A. Differential Pressure Measurements

Observation of the differential (pressure) transducer response was done using the HP 7090A plotting and measurement system. Input to the three channels of the system were the following.

1. CEESI Honeywell differential pressure transducer
2. Test loop differential pressure transducer
3. CEESI Mensor transducer connected to the orifice static pressure (tap).

Observations over several time intervals were made. Most of these were taken over a 5-minute interval to match the data collection time for a single run of the data acquisition system. Figure B1 shows a plot of the three channels taken at the same time as run 565. Two observations can be made, (1) a periodic variation in the signal is observed, and (2) there may be significant shifts in the differential pressure signal during the course of a run. Both differential pressure transducers showed very similar variation signatures. The similarity between the two suggests that the source of the variation is common and is either electrical, a true differential pressure variation or a combination of both. Simple tests of the transducer response variation with the transducers valved off and crossed over show that the source of a minor component is electrical in nature. The variation increased substantially when differential pressure was re-applied.

(The following section was not included in the original report. It is given here as an explanation of the values listed in table 2.)

B. Comparison of Test Loop Instrumentation Response with the Diagnostic Instruments

Table 3 lists the results of test parameters observed by the normal test loop instruments and those brought to the test site for diagnostic tests. The test runs listed were collected over a period of several days. Generally, all of the measured parameters show good agreement between the diagnostic instruments and the test loop instruments. The values listed for the diagnostic instruments were obtained from manual observations of the response. The test loop instrument values were obtained from the run-time sheets printed by the computer after each test run.

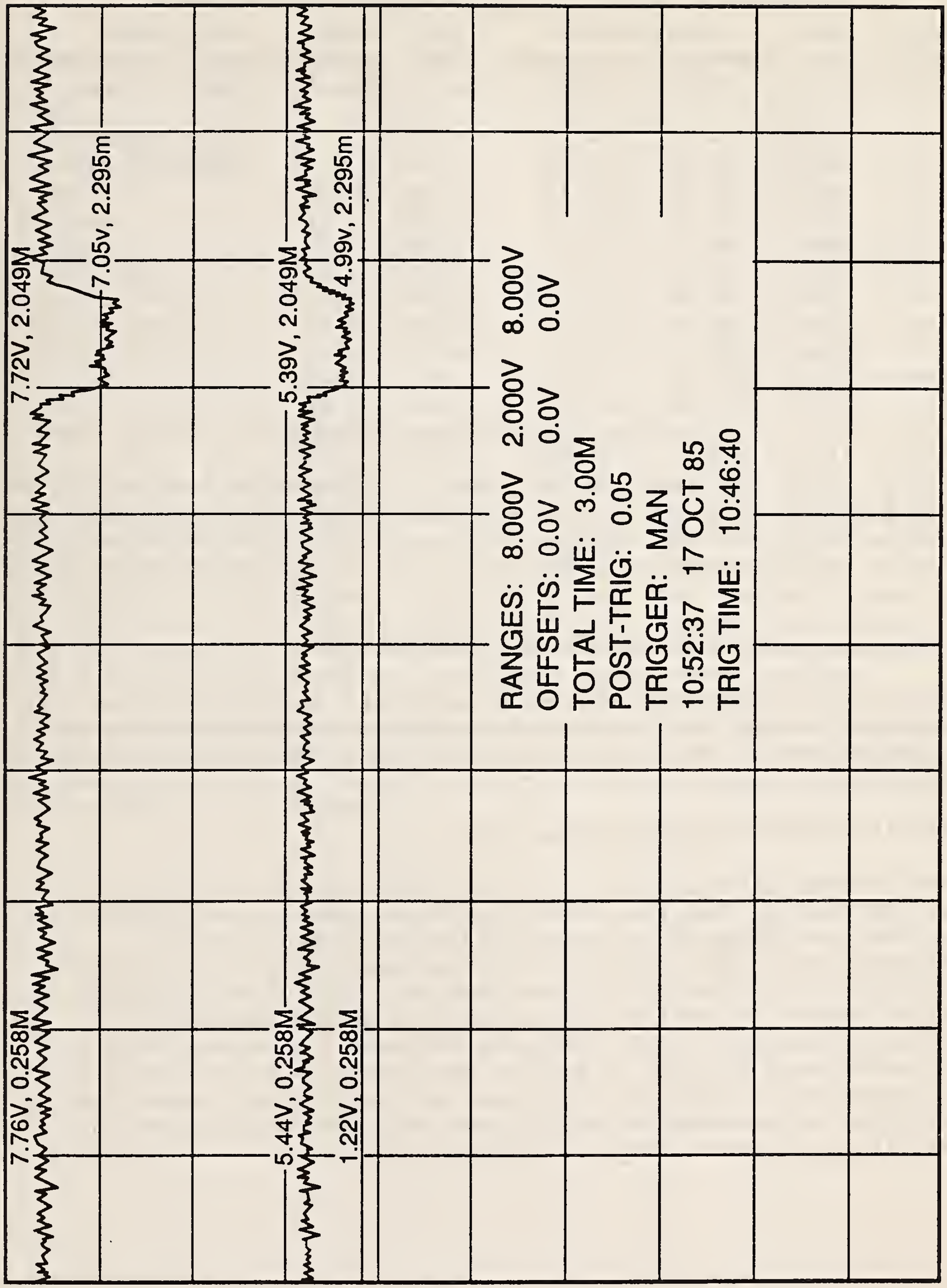


Figure B1. Differential pressure traces taken during test run 565.

Table 3. Tabulation of response comparisons

Run	Orif. Temp.		Orif. Press.		Diff. Press.		Noz. Press.	
	TC	RTD	Mensor	Rosemount	CEESI*	NGPLA	Mensor	Rosemount
	(Degrees F)		(Psia)	(Psia)	(In. of Water)		(Psia)	(Psia)
543	94.6	94.29	724.58	724.58			723.3	723.1
544	94.6	94.23	722.51	722.80			721.3	721.3
548	93.1	92.82	712.21	712.22	47.98	47.96		
557	92.5	92.16	675.33	675.60	45.16	45.18		
562	91.8	91.67	640.58	641.06	42.85	42.82		
563	87.8	87.60	653.12	653.44	43.37	43.43		
564	87.7	87.47	645.36	645.58	42.89	42.93		
565	88.9	88.78	629.00	629.39	105 68	106.49		
566	89.2	89.06	627.41	628.06	106.76	106.40		
567	90.5	90.36	636.51	637.12	11.82	11 73		
568	91.4	91.23	642.46	642.89	11.88	11.89		
569	76.5	76.34	694.56	695.31	60.82	60.97		
570	77.5	77.43	704.90	705.58	61.71	61.84		
571	73.2	73.17	707.40	707.79	129.35	129.44	710.15	710.11
572	73.2	73.08	708.90	708.76	129.62	129.68	711.20	711.08
573	70.4	70.31	702.70	702.96			706.50	706.40
574	70.4	70.27	702.80	703.09			706.60	706.90

4. Chromatograph Response and Gas Standards Checks

Diagnostic tests of the chromatograph response were performed. NGPLA made available access to a second chromatograph as part of these tests which allowed several intercomparisons to be made. These are discussed in detail below.

A. Amarillo Calibration Standard Gas Test

The ENCAL chromatograph located at the main office of Station 113 (Joliet) was used to test the composition of the Amarillo Gas Standard. The cylinder containing the standard gas had been taken to the chromatograph at the main office by NGPLA personnel prior to this visit. (The results of that test are included here as a form of documentation of NGPLA's efforts to identify sources of error in the measurement systems and procedures). This instrument (located in the main office) used a gas standard prepared to NGPLA's specifications for Station 113 with a composition between the Gulf Coast and Amarillo gas compositions. Table 3 gives the measured and manufacturer specified compositions for the Amarillo gas standard prepared for this project.

Table 4.

Component	Specified Composition	Measured Composition
C_6+	0.1001	0.09714
Nitrogen	2.701	2.6573
Carbon Dioxide	0.5990	0.5833
Methane	91.3973	91.5547
Ethane	3.7516	3.6633
Propane	1.001	0.9995
Isobutane	0.1500	0.1515
Normal Butane	0.0999	0.0986
Isopentane	0.1001	0.0995
Normal Pentane	0.1000	0.1013

B. Tests of Test Loop ENCAL Chromatograph Response

The initial test objective was to determine the amount of change in the composition of the test gas measured by the test loop ENCAL induced by using one of the calibration gases with the opposite test gas, i.e., the Amarillo calibration gas for the chromatograph standard with the test loop running Gulf Coast gas. For this test the test loop was blocked so that there was no flow in the loop. In this way the gas being tested by the chromatograph would be stable in composition. Then both calibration gases were used in succession to perform several composition measurements of the test gas. Differences between the two composition measurements would then give an estimate of the effect on the gas properties of operating the chromatograph in this way as has been done during the 1985 testing at Joliet. Table 5 lists the test gas composition using both calibration gas standards.

Table 5. Test gas compositions using both calibration standards on the test loop ENCAL chromatograph

Date:	10/16	10/16	10/16	10/16	10/16	10/16	10/16
Time:	12:22	12:34	12:47	14:04	14:16	14:29	14:42
Calib. Gas	Gulf Coast	Gulf Coast	Gulf Coast	Amar.	Amar.	Amar.	Amar.
Component							
C_6+	.02906	.02946	.02926	.02937	.02912	.02906	.02910
N_2	.36384	.36619	.36057	.34768	.34613	.34986	.35015
Methane	95.68430	95.67700	95.66610	95.6118	95.6142	95.6058	95.61020
CO_2	.69508	.69276	.69574	.70943	.70931	.70977	.70966
Ethane	2.31571	2.31875	2.32698	2.37968	2.37820	2.37853	2.37860
Propane	.55849	.56063	.56356	.56730	.56510	.56504	.56497
I-Butane	.14005	.14008	.14142	.14032	.13982	.13979	.13955
N-Butane	.12443	.12592	.12680	.12659	.12790	.12932	.12889
I-Pentane	.05607	.05563	.05475	.05286	.05710	.05772	.05680
N-Pentane	.03296	.03355	.03478	.03499	.03315	.03511	.03392
BTU	1033.9	1034.0	1034.2	1034.6	1034.6	1034.7	1034.6
S.G.	.5864	.5864	.5865	.5869	.5869	.5870	.5869

C. Composition of Test Loop Gas Taken From a Sample Cylinder

A sample of gas was taken from the test loop (Gulf Coast was the gas type) in one of the stainless steel sample containers supplied by Mr. Fling. It was analyzed on both ENCAL chromatographs located at the test site. One was the ENCAL located at the test loop and the other was the main office ENCAL chromatograph used in the tests described in section A above. Table 5 gives the results of several analyses using the main office ENCAL which had as its standard the specially prepared mixture made by Matheson. This sample bottle was then brought to the test loop and connected to the ENCAL there which had been calibrated with the Amarillo gas standard. Table 7 lists successive compositions for the gas drawn from this sample bottle.

Table 6. Sample bottle of Gulf Coast gas analyzed by encal in office using Matheson calibration gas

Date:	10/16	10/16	10/16	10/16
Time:	1342	1356	1410	1424
Calib. Gas	Matheson	Matheson	Matheson	Matheson
C_6+	.05115	.05631	.05898	.06000
Nitrogen	.44034	.37154	.35358	.35433
Methane	95.57980	95.62870	95.63170	95.6288
CO	.65523	.65580	.65671	.65876
Ethane	2.35533	2.36082	2.37018	2.37177
Propane	.57128	.57399	.57387	.57491
I-Butane	.13912	.14097	.14097	.14076
N-Butane	.12522	.12680	.12654	.12780
I-Pentane	.50135	.05120	.05247	.05195
N-Pentane	.03112	.03387	.03494	.03088
BTU	1034.8	1036.0	1036.4	1036.3
S.G.	.5871	.5871	.5872	.5872

NOTE: This sample bottle to be sent to Wayne Fling for further analysis.

Table 7. Sample bottle of Gulf Coast analyzed on encal at test loop (using Amarillo calib. gas) after sample analyzed in office

Date:	10/16	10/16	10/16	10/16	10/16	10/16	10/16
Time:	15:07	15:20	15:33	15:46	15:58	16:11	16:24
C_6+	.02278	.02479	.02578	.02685	.02761	.02885	.02902
Nitrogen	.44798	.39926	.37451	.36632	.36331	.35495	.35222
Methane	95.53660	95.57170	95.59830	95.60120	95 59620	95.6032	95 60910
CO	.70705	.70859	.70737	.70784	.70888	.70963	.70962
Ethane	2.37331	2.37654	2.37427	2.37389	2.37983	2.37923	2.37566
Propane	.56143	.56233	.56370	56457	.56554	.56487	.56468
I-Butane	.13807	.13891	.13926	.13956	.13933	.13950	.13978
N-Butane	.12652	.12733	.12823	.12877	.12864	.12882	.12864
I-Pentane	.05432	.05711	.05544	.05712	.05700	.05714	.05769
N-Pentane	.03198	.03339	.03310	.03388	.03367	.03383	.03362
BTU	1033.1	1033.8	1034.1	1034.4	1034.4	1034.6	1034.6
S.G.	.5869	.5869	.5868	.5869	.5869	.5869	.5869

5. Comparison of DDR-6000 Response to the Ametek RK-300.

The Ruska DDR-6000 response was tested at atmospheric pressure using the Ametek deadweight tester. The test sides of both instruments were connected together. Nitrogen was used as the pressure source for the deadweight tester. The manufacturer's accuracy specification for the Ametek used is 0.015% for differential pressures greater than 30 inches of water and 0.025% for differential pressures less than 30 inches. Table 8 gives the results of this test.

Table 8. DDR-6000 calibration
2nd test

Obs.	Ametek Press. (In. Water)	DDR Indication (Volts)	DDR Zero Adjusted (Volts)	Actual Diff. Press. (In. Water)	DDR Press. -- (In. Water) --	Diff.
1	0	0.01529	0.0000	0.000	0.000	.000
2	10	0.23376	0.24906	9.998	10.009	+.011
3	20	0.48255	0.49785	19.995	20.007	+0.15
4	50	1.2290	1.2443	49.988	50.004	+0.16
5	100	2.4729	2.4882	99.976	99.992	+0.16
6	150	3.7169	3.7322	149.964	149.984	+.020
7	200	4.9608	4.9761	199.952	199.973	+.021
8	250	6.2050	6.2203	249.940	249.973	+.033
9	200	4.9608	4.9761	199.952	199.973	+ 021
10	100	2.4730	2.4883	99.976	99.996	+.020
11	20	0.48260	0.4979	19.995	20.009	+.014
12	20	0.01530	0.000	0.000	0.000	.000

6. Thermocouple Measurement Results

Table 9 gives the temperatures of the thermocouples at the four installations given in the auxiliary equipment section. (The water temperature refers to the upstream, heated water bath, the skip temperature is that obtained from a thermocouple mounted on the meter tube surface, the upstream gas temperature is measured by an insertion thermocouple in a thermometer well upstream of the Sprenkle flow conditioner, and the orifice temperature was taken from the test loop instruments.)

Table 9. Temperature vs. time
CEESI thermocouples

10/16/85 Flow Through the FE-7/8-1B Plate

Time	Water Temp.	Skin Temp.	Upstream Gas Temperature	Orifice Temp.
7:30	113.0			86.0
8:10	130.0			93.0
8:24	129.9	89.5	95.4	92.2
8:40	127.8	89.4	95.3	92.0
8:55	127.0	89.1	94.7	91.8
9:25	125.8	89.4	94.7	91.5
9:42	125.0	89.5	94.8	92.2
12:35	121.3	89.5	93.3	91.6
1:35	119.8	90.9	92.6	91.3
*2:00	118.8	88.7	91.9	84.5
2:30	116.0	86.0	90.2	81.5
	10/17/85	Flow through 6B Plate		
1:30	150.0	74.7	74.6	74.7
1:40	161.0	77.3	77.2	77.3
2:00	167.3	73.7	73.2	73.3
2:10	171.0	73.4	73.1	73.2
2:30	168.8	70.5	70.5	70.5
2:45	171.9	70.9	70.4	70.4

*Line Shut-in for ENCAL Evaluation at 2:00 PM.

7. Comparison of Compressibility Factor Values For Selected Gas Compositions

Tables 10-12 list compressibility and supercompressibility factors for the test gas compositions obtained from the test loop ENCAL chromatograph for both calibration gases. The differences between the two types of calibration gas for the same test gas is the source of a change in the compressibility and supercompressibility factors of below 0.02%. Table 12 gives these factors calculated for the composition in table 11 but with the C_6+ fraction set to zero. Neglecting the C_6+ fraction induces a systematic change in the values of these factors of at most 0.03%.

Table 10. Gulf Coast test gas using gulf coast calibration gas taken on Oct. 15, 1985 at 12:47 using the test loop ENCAL chromatograph

Compressibility Factors

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	0.9371	0.9415	0.9455	0.9493	0.9527	0.9560
450	0.9293	0.9343	0.9389	0.9431	0.9470	0.9506
500	0.9215	0.9271	0.9322	0.9370	0.9413	0.9454
550	0.9138	0.9200	0.9256	0.9309	0.9357	0.9402
600	0.9061	0.9129	0.9191	0.9248	0.9301	0.9350
650	0.8985	0.9059	0 9126	0.9189	0.9246	0.9299
700	0.8909	0.8989	0.9062	0.9130	0.9192	0 9249
750	0.8834	0.8920	0.8999	0.9071	0.9138	0 9199
800	0.8760	0.8852	0 8937	0.9014	0.9085	0.9151
850	0.8687	0.8785	0.8875	0.8957	0.9033	0.9103

Computed Supercompressibility Factors F_{PV}

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	1.0319	1.0295	1.0273	1.0253	1.0234	1.0217
450	1.0362	1.0335	1.0309	1 0286	1.0265	1.0245
500	1 0406	1.0374	1.0346	1 0320	1.0296	1.0274
550	1 0450	1.0415	1.0383	1.0353	1.0327	1.0302
600	1.0494	1.0455	1.0419	1.0387	1 0358	1.0331
650	1.0538	1.0495	1.0456	1.0421	1.0388	1 0359
700	1.0583	1.0536	1.0493	1.0454	1.0419	1.0387
750	1.0628	1.0576	1.0530	1.0488	1.0450	1.0415
800	1.0673	1.0617	1.0567	1.0521	1 0480	1.0442
850	1.0718	1.0658	1 0603	1.0555	1.0510	1 0470

Measured Gas Composition

Nitrogen	0.3606	N Butane	0.1268
Carbon Dioxide	0.6957	IsoButane	0.1414
Methane	95.6661	N Pentane	0.0348
Ethane	2.3270	IsoPentane	0.0548
Propane	0.5636	C_6+ Average	0.0293

Table 11. Gulf Coast test gas using Amarillo calibration standard taken on Oct. 16, 1985 at 14:42 using the test loop ENCAL chromatograph

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	0.9370	0.9414	0.9455	0.9492	0.9527	0.9559
450	0.9292	0.9342	0.9388	0.9430	0.9469	0.9506
500	0.9214	0.9270	0.9321	0 9369	0.9412	0.9453
550	0.9137	0.9199	0.9255	0.9308	0 9356	0.9401
600	0.9060	0.9128	0.9190	0.9247	0.9300	0.9349
650	0.8983	0.9057	0.9125	0.9187	0 9245	0.9298
700	0.8908	0.8988	0.9061	0.9128	0 9190	0.9248
750	0.8832	0.8919	0 8997	0.9070	0.9136	0.9198
800	0.8758	0.8850	0.8935	0 9012	0.9083	0.9149
850	0.8684	0.8783	0.8873	0.8955	0.9031	0.9101

Computed Supercompressibility Factors, F_{PV}

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	1.0319	1.0295	1.0273	1.0253	1.0234	1.0217
450	1.0363	1.0335	1.0310	1.0287	1.0265	1.0246
500	1.0406	1.0375	1.0346	1.0320	1.0296	1.0274
550	1.0450	1.0415	1.0383	1.0354	1.0327	1.0303
600	1.0495	1.0456	1.0420	1.0388	1.0358	1.0331
650	1.0539	1.0496	1.0457	1.0422	1.0389	1.0359
700	1.0584	1.0537	1.0494	1.0455	1.0420	1.0388
750	1.0629	1.0577	1 0531	1.0489	1.0451	1.0416
800	1.0674	1.0618	1.0568	1.0522	1.0481	1.0443
850	1.0719	1.0659	1.0605	1.0556	1.0511	1.0471

Measured Gas Composition

Nitrogen	0.3501	N-Butane	0.1289
Carbon Dioxide	0.7096	IsoButane	0 1398
Methane	95.6082	N-Pentane	0.0339
Ethane	2.3786	IsoPentane	0.0568
Propane	0.5650	C_6+ Average	0.0291

Table 12. Compressibility and supercompressibility computed for the same gas composition as in table 9 with the C_6+ fraction set to zero and the composition renormalized

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	0.9373	0.9417	0.9457	0.9495	0 9529	0.9561
450	0.9296	0.9345	0.9391	0.9433	0.9472	0.9508
500	0.9218	0.9274	0.9325	0.9372	0.9415	0 9456
550	0.9141	0.9203	0.9259	0 9311	0.9359	0.9404
600	0.9065	0 9132	0.9194	0.9251	0.9304	0 9352
650	0.8989	0.9062	0.9130	0.9192	0.9249	0.9302
700	0.8913	0.8993	0.9066	0.9133	0 9195	0.9252
750	0.8839	0.8924	0.9003	0.9075	0.9141	0 9202
800	0.8765	0.8856	0 8940	0.9017	0.9088	0.9154
850	0.8691	0.8789	0.8879	0 8961	0.9036	0.9106

Computed Supercompressibility Factors, F_{PV}

Pressure	Temperature (°F)					
psia	50	60	70	80	90	100
400	1.0318	1.0294	1.0272	1.0252	1.0233	1.0216
450	1.0361	1.0333	1.0308	1.0285	1.0264	1.0244
500	1 0404	1.0373	1.0345	1.0319	1.0295	1.0273
550	1.0448	1 0413	1.0381	1.0352	1.0326	1.0301
600	1.0492	1.0453	1.0418	1.0386	1.0356	1.0329
650	1.0536	1.0493	1.0455	1.0419	1.0387	1.0357
700	1.0581	1.0534	1 0491	1 0453	1.0418	1.0385
750	1.0625	1.0574	1.0528	1.0486	1.0448	1.0413
800	1.0670	1.0615	1.0565	1.0519	1.0478	1.0441
850	1.0715	1.0655	1.0601	1.0552	1.0508	1.0468

The gas composition is the same as that of Table 9 except for the C_6+ fraction which is set to zero and the composition renormalized.

Gas Composition

Nitrogen	0.3607	N-Butane	0.1268
Carbon Dioxide	0.6959	IsoButane	0.1415
Methane	95.6940	N-Pentane	0.0348
Ethane	2.3277	IsoPentane	0.0548
Propane	0.5638	C_6+	0.0

8. Differential Pressure Signal Quality

The quality of the differential pressure signal was observed throughout this set of tests. The method used was plotting of the differential pressure transducer signals such as is shown in figure 1. The variation in differential pressure signals seen in the plots is rather low in frequency. The effects of higher frequency components in the gas pressure could not be observed directly by the instrumentation available in this work. If such high frequency pressure waves are present in the pipeline and test loop, their effect on the response of the transducers and their associated piping is not known and is not measurable with the present instrumentation system. However, a change in the response of the differential pressure transducers might be seen for differing conditions of the test loop or for the pipeline system around the Joliet station. A change in conditions would be expected to change characteristics (and frequency) of the pressure waves in the system if these were present. As a test of this assumption a change in the pipeline configuration upstream of the station was done during a data collection pass consisting of four runs.

a. Pipeline Condition - An initial data collection pass of four runs was made with the pipeline operating in its normal condition at that time in which gas was being fed to the Howard St. Line through two 8-inch valves located 1/4-mile from the station. Station personnel stated that these were small valves for the flow rate being sent to Howard Street. It could be assumed that the level of acoustic noise in the pipeline induced by these valves would be higher with them open than with them closed.

b. The two 8-inch valves were shut and the second data pass was begun. No changes were made in the test loop conditions. During the fourth run in the pass, the valves were opened. The results of this test are given in table 13.

Table 13 lists results for the initial data collection pass of four runs which were run numbers 549 through 552. The valves were closed during runs 553 - 555. These are marked by the asterisks in the table. The difference in variation in the results are quite substantial. The range of variation in the differential pressure values decreases by approximately a factor of 3. The variation in the discharge coefficient for the four initial runs is 0.35% relative to 0.11% for the three runs taken with the valves off. The variation in the signals increased as the valves were opened. These data were collected using the 0.1 beta ratio plate of the 6-inch meter run.

Table 13. Observed pipeline disturbance effects

Run No.	Orifice Press. (Psi)	Reynolds Number	Discharge Coefficient	Diff. Press. (In. Water)	Range of Diff. Press. (%)
549	555.4	228,511	0.5959	37.388	17.51
550	557.8	229,587	0.5967	37 448	21.66
551	560.3	230,583	0 5947	37.875	17.69
552	563.2	231,720	0.5968	37.817	18.13
553*	580.9	239,140	0.5948	39.288	6.98
554*	587.6	241,943	0.5952	39.688	6.97
555*	593.9	244,544	0.5955	40.087	6.33
556	598.3	246,488	0.5977	40.089	12.87

* Eight-inch valves closed during this run

A similar test of the system was made with the 0.75 beta ratio plate installed in the meter run, in which a main shut off valve upstream of the meter run in the test loop was partially closed in an attempt to isolate the orifice meter somewhat from pipeline noise or disturbances. Minimal change in the discharge coefficient values for the fully open or partially closed condition of the valve were observed.

Near the end of the tests it was suggested by NGPLA personnel that damping the transducers may have an effect on the differential pressure values and consequently the discharge coefficient values. After the authors left the site the damping of the transducers was changed sequentially and data collected for each value. The damping time constants used were 0.3, 1.0, 2.0, and 5.0 seconds. Normally the transducers have been operated with no damping. Minimal change in the discharge coefficient values were observed as the damping time constant was changed.

III. Conclusions

With the use of redundant measurements made during this evaluation, the instrumentation system at the Joliet Test Site is operating within its expected specifications. All calibration procedures used by the NGPLA operating personnel are adequate and are being followed correctly. At this time quantitative evaluation of the effect of the original computational method agreed by the committee for this project relative to one based on Starling's recent publication of AGA Draft Report No. 8 cannot be performed until critical flow factor calculations based on Starling's method are complete. The originally agreed method utilizes NX-19 for computation of the gas properties at the orifice and Johnson's method for calculation of mass flow rate through the nozzle. Preliminary calculations of the compressibility factors using the three methods show that the difference between Johnson's and Starling's compressibility values for the same gas composition differ. The magnitude of the difference may be significant to the results obtained to date. As an example the following calculation was made for Run No. 563.

Orifice Pressure - 653.44 Psia	Nozzle Pressure - 653.57
Temp. = 87.60°F	Temp. = 85.12°F
Starling Z = 0.92356	Starling Z = 0.92214
NX-19 Z = 0.92702	Johnson Z = 0.92129

Starling Z - NX-19 Z = -0.00346
Starling Z - Johnson Z = +0.00085

It is expected that the use of a unified method for calculation of the gas properties for the test data will result in improved results and may reduce the scatter in the results since the differences between NX.19 and Johnson's methods relative to Starling will be pressure, temperature and composition dependent. The above example shows that changes of approximately 0.4 percent may be seen if the proper gas property calculation is performed.

IV. Recommendations

1. It is recommended that further testing at the site be limited to high differential pressure values, i e., 50, 100, and 200 inches of water.

2. Although gas property effects induced by measured compositional changes in the gas appear to be minimal in the compressibility factors, the magnitude of the effect of these changes on the critical flow factor is not yet known for values based on the recent correlation of Starling in AGA Draft Report No. 8. The computational capability to calculate the critical factor value is being pursued by Dr. Whetstone. When these calculations can be made they will be, and an addendum to this report will be made.

This report was presented to the Orifice Steering Committee. No single source of variation in the measurement system could be identified as being sufficiently large to cause the offset in the results between the data taken in 1984 and 1985. Approximately a month of testing was performed after these diagnostic tests were completed in the hope that the source of the systematic effects could be isolated at a latter time and appropriate corrections applied to the data during analysis. No such source was identified.

References

B1. Whetstone, J. R., Cleveland, W. G., Baumgarten, G. P., Woo, S., and Croarkin, M. C., "Measurements of Coefficients of Discharge for Concentric Flange-Tapped Square-Edged Orifice Meters in Water Over the Reynolds Number Range 1,000 to 2,700,000", NBS Report to be published.

B2. Certain commercial equipment and instruments are identified in this paper in order to describe the experimental procedures and results adequately. In no case does such identification imply recomendation or endorsement by the National Bureau of Standards nor does it imply the material or equipment is necessarily the best available for the purpose.

APPENDIX C

Derivation of the Coefficient of Discharge Relation and Associated Units Conversion Factors

A. Theoretical Mass Flow Rate

The arrangement of an orifice meter placed in a pipeline with differential pressure taps located in the adjacent flanges is illustrated in figure C1. The derivation of the theoretical mass flow rate is based on the following assumptions:

1. the velocity profile is uniform (one-dimensional) with no boundary layers at the pipewall or the surface of the orifice plate,
2. the pipeline is horizontal and of uniform, circular cross section, and
3. no energy loss occurs between the pressure taps.

The parameters used in the derivation are:

P_1 = pressure at the upstream orifice tap,
V_1 = average velocity in the pipe upstream of the orifice plate,
D = diameter of the meter tube,
A_1 = $\pi D^2/4$ = area of the meter tube through which the fluid flows,
P_2 = pressure at the downstream orifice tap,
V_2 = average velocity of the fluid through the orifice,
d = diameter of orifice
A_2 = $\pi d^2/4$= area of the orifice,
$\dot{m}_1$ = mass flow rate through the meter tube,
$\dot{m}_2$ = mass flow rate through the orifice,
ρ_1 = density of the fluid flowing in the meter tube,
ρ_2 = density of the fluid flowing in the orifice,
β = d/D, the orifice beta ratio,
u = internal energy of the flowing fluid per unit mass,
h = enthalpy of the flowing fluid per unit mass,
s = entropy of the flowing fluid per unit mass,
R = universal gas constant,
T = absolute temperature,
c_P = specific heat of fluid at constant pressure,
c_V = specific heat of fluid at constant volume,
γ = c_P/c_V, the ratio of specific heats,
r = P_2/P_1, the ratio of the pressure at the upstream pressure tap to that at the downstream pressure tap,
ΔP = P_1-P_2, the differential pressure developed across the orifice meter.

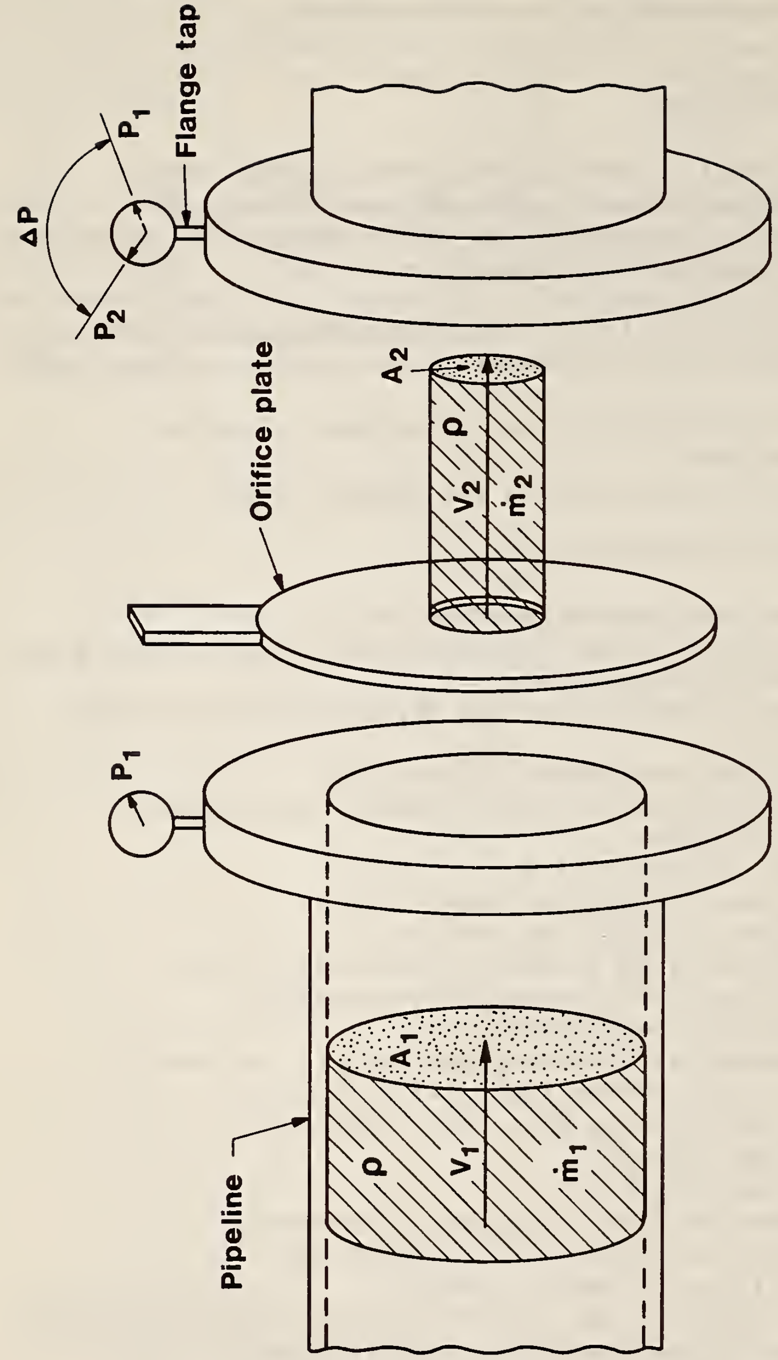

ΔP
P_1
P_2
Flange tap
Orifice plate
A_2
ρ
V_2
$\dot{m}_2$
P_1
A_1
ρ
V_1
$\dot{m}_1$
Pipeline

Figure C1. Orifice meter installation in a pipeline

The physical principles needed to derive the mass flow rate are the continuity equation (conservation of mass) and the energy equation (conservation of energy).

The mass flow rate of fluid passing through the meter tube or the orifice may be expressed as a function of the average fluid velocity, V, the area of the tube or orifice, A, and the density of the fluid, ρ:

$$\dot{m} = \rho AV. \tag{C.1}$$

The continuity equation requires that

$$\dot{m}_1 = \dot{m}_2 , \tag{C.2}$$

or

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 . \tag{C.3}$$

The energy equation relates the properties of the flowing fluid at position 1 to those at position 2. In SI units,

$$\frac{P_1}{\rho_1} + \frac{1}{2} V_1{}^2 + u_1 + gZ_1 = \frac{P_2}{\rho_2} + \frac{1}{2} V_2{}^2 + u_2 + gZ_2 , \tag{C.4}$$

where Z_1 and Z_2 are the elevations of the points at which the pressures are measured and g is the local acceleration due to gravity. With the assumption that the pressure taps are at the same elevation, one can rewrite this in terms of the enthalpy per unit mass:

$$h_1 + \frac{1}{2} V_1{}^2 = h_2 + \frac{1}{2} V_2{}^2 . \tag{C.5}$$

Eliminating V_1 using eq (C.3) and forming $\rho_2 A_2 V_2$, one obtains the theoretical mass flow rate in the form:

$$\dot{m} = (\rho_2 \pi d^2/4)[2(h_1 - h_2)]^{1/2}[1-\beta^4(\rho_2/\rho_1)^2]^{-1/2} . \tag{C.6}$$

To proceed further, one needs to express the enthalpy difference, $h_1 - h_2$, in terms of parameters that are either measured or calculated. If it is assumed that the fluid is an ideal gas, then

$$P/\rho = RT, \tag{C.7}$$

where R is the universal gas constant and T is the absolute temperature. With the assumption that the change in state of the fluid between the pressure taps is reversible and adiabatic, one also has

$$P_1/\rho_1{}^{\gamma} = P_2/\rho_2{}^{\gamma} = P/\rho^{\gamma} = \text{constant} = c, \tag{C.8}$$

where γ is the ratio of the specific heats. Using this equation, one can integrate the thermodynamic relation $(\partial h/\partial P)_s = 1/\rho = c/P^{1/\gamma}$ to obtain

$$h_1 - h_2 = c \frac{\gamma}{\gamma - 1} P_1{}^{(\gamma-1)/\gamma}[1 - r^{(\gamma-1)/\gamma}], \tag{C.9}$$

where $r = P_2/P_1$ is the ratio of the pressure at the downstream pressure tap to that at the upstream pressure tap.

Combination of eq (C.9) and (C.6) leads, upon rearrangement, to an expression for the theoretical mass flow rate in terms of the differential pressure, $\Delta P = P_1 - P_2$, developed across the orifice meter:

$$\dot{m} = \frac{\pi}{2\sqrt{2}} \frac{d^2 Y \ (\rho_1 \Delta P)^{1/2}}{(1-\beta^4)^{1/2}} \tag{C.10}$$

where

$$Y = \left[r^{2/\gamma} \ \frac{\gamma}{\gamma - 1} \ \frac{1 - r^{(\gamma-1)/\gamma}}{1 - r} \ \frac{1 - \beta^4}{1 - \beta^4 r^{2/\gamma}} \right] \tag{C.11}$$

Here Y is the adiabatic expansion factor, which depends on the diameter ratio, b, the pressure ratio, r, and the ratio of specific heats, γ.

The value of ρ_1 in eq (C.10) should be computed at P_1, T_1 using the general equation of state of the actual gas.

Equation (C.11) is generally applicable to flow element geometries where the radial expansion of the fluid is confined by the shape of the element, i.e., in nozzles and venturis. However, the abrupt geometries of orifices allow expansion of the gas radially as well as longitudinally, and the adiabatic conditions assumed in developing eq (C.11) do not apply for orifices. An empirical method for determining the expansion factors for orifices was developed by Buckingham [C1] and modified by Bean and is the widely used basis for calculation of expansion factors for orifice flows. This method is contained in API 2530/AGA 3 for up stream and downstream static pressure taps for the flange tapped orifice meter. This relation, eq (C.12), was used in analyzing test run results.

$$Y_2 = [1 + x_2]^{1/2} - (0.41 + 0.35\beta^4)\ x_2/[k(1 + x_2)] \qquad (C.12)$$

where x_2 = the ratio of differential pressure to absolute static pressure at the downstream tap.

B. Orifice Thermal Expansion Factor

Most materials expand or contract as their temperature increases or decreases. Consequently, a factor, F_a, must be introduced to correct the area of the orifice when the operating temperature differs appreciably from that at which the area was determined. This is done by replacing d^2 in eq (C.10) by $F_a d^2$.

C. Definition of the Discharge Coefficient

The derivation of eq (C.10) is based on the assumptions given at the beginning of this Appendix. The derivation neglects many effects that occur in actual orifice meter configurations, e.g., effects due to non-uniformities in the velocity profile , turbulence, frictional losses, orifice edge sharpness, the finite thickness of the orifice plate, pressure tap location, etc. The inability to model these effects realistically results in a significant difference between the actual mass flow rate through an orifice meter and that predicted theoretically (eq 10). One corrects for this difference by introducing a correction factor defined as the ratio of the actual mass flow rate to the theoretical mass flow rate given by eq (C.10) modified to include the orifice thermal expansion factor. This ratio is customarily called the coefficient of discharge, or the discharge coefficient, and denoted by C_d. From eq (C.10), C_d is given by

$$C_d = \dot{m}(1-\beta^4)^{1/2}\left[\frac{\pi}{2\sqrt{2}}\ {}^2YF_a(\rho_1\Delta P)^{1/2}\right]^{-1} \qquad (C.13)$$

Because C_d is a ratio, the value of C_d is independent of the system of units in which the various quantities are measured.

D. Unit Conversion Factors

Because the quantities in eq (C.12) are often measured in incommensurate units, it is customary to replace the factor of $\pi/2\sqrt{2}$ in the definition of the discharge coefficient by a factor, N, which depends on the actual units used. With this replacement, eq (C.12) is identical to eq (1) in section II.

APPENDIX D

Report to the American Petroleum Institute
on
Experimental and Computed Values
of
Natural Gas Compressibility for Samples of Gas Similar to Those Used in the Joliet Orifice Meter Testing Program

The report reproduced here was submitted to the American Petroleum Institute by the University of Oklahoma. It is reproduced here in keeping with the intent of NBS and API to document this orifice test program as completely as practicable. No alterations have been made to the report with the exception of placing page numbers on each page of the textual portion of the report to be consistent with the page numbering system of this document. The original report contained voluminous tables in various of the appendices. These tables have not been reproduced here. The appendices containing comparision of experimental and calculated values have been included.

FINAL REPORT TO
AMERICAN PETROLEUM INSTITUTE
ON

CONTINUED EXPERIMENTAL AND ANALYTICAL SERVICES IN SUPPORT OF THE API NATURAL GAS FLOW TEST PROGRAM

By

Rex T. Ellington, Investigator
Kenneth E. Starling, Investigator
Mark J. Hill, Laboratory Supervisor
Jeffery L. Savidge, Research Associate

School of Chemical Engineering and Materials Science
University of Oklahoma

Norman, OK 73019

May 15, 1986

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FINAL REPORT ON
CONTINUED EXPERIMENTAL AND ANALYTICAL SERVICES
IN SUPPORT OF
THE API NATURAL GAS FLOW TEST PROGRAM

SUMMARY

INTRODUCTION

Pursuant to a proposal presented by the University of Oklahoma on August 15, 1985, a contract for continued work to support API's test program was signed on November 12, 1985. Under this contract, the Investigators were obligated to carry out the following work:

1. Two evacuated cylinders were to be sent to NGPL to be filled with gas from the pipeline under test. One cylinder will be sent to Cities Service for analysis and the other will be sent to O.U. for compressibility factor measurements. (This gas became known as the Amarillo gass.)

2. Information supplied by API regarding composition variation of the pipeline gas will be tabulated with respect to composition. Compressibility factor and C* calculations will be performed for the maximum, minimum and average compositions of both the Gulf Coast and Amarillo gas compositions supplied by API on July 12, 1985. However, these compositions must be modified to include water content. Efforts will be made to develop simple interpolation tables for interpolating compressibility factor and C* variations from the test gas furnished to OU and the limits of variation defined by compositions supplied by API. Accuracy sought for the interpolation tables will be equal to or better than the guaranteed discharge coefficient for the flow nozzle, i.e., 0.1%. Estimation of accuracy will be included with the tables.

3. Compressibility factor data runs are to be made with O.U.'s Z-Meter in 50 psi increments from 150 psi to cylinder pressure at nominally 60 F and 79 F. One duplicate run is to be made at each pressure and temperature with a difference in Z of no greater than 0.05%. Cryogenic compression will be

used to obtain data in the 500 to 900 psi range. The composition supplied by API, including water vapor will be used to calculate the compressibility factor for each data point and compared with the experimental value and reported.

4. Compressibility factor tables will be computed for the test gas for 1 psi and 0.5 F intervals up to 600 psi. A C* table will be developed for the same increments of temperature and pressure. The estimated dew point curve for the experimental gas for the range of interest. The outlet nozzle conditions for a number of inlet conditions will be plotted to show when condensation could occur.

The composition of the gas was supplied by API but was found to be in error. The correct composition is given in Table 1, Appendix A.

EXPERIMENTAL DATA

The experimental equipment and procedures are exactly the same as reported in the April 15, 1985 report on the first part of the API work. Oral presentation of the accuracy and precision of the work was made at steering committee meeting in Tulsa, Dec. 5, 1985. A request was made that some of this information be included in the final report. O.U. agreed to this inclusion and is providing it in the form of the attached reprint of a paper presented at the annual GPA meeting. In this way, it can be done without cost. The purpose of this inclusion is to assure API that the quality of the data is that of the best research data. One factor worth noting is that the precision of the data has improved from +/- 0.03% to +/- 0.02% from the first API test to the second.

The primary data for the new test work are presented in Tables 1 and 2, and the accompanying precision plots are given in Figures 1 and 2, Appendix A. It should be noted that more tests than the one replication specified by the contract has been made in every case (also at no cost to API). Runs were usually repeated if they differed by more than 30 parts in 100,000. This is significantly less difference than the 0.05% stipulated in the proposal.

The data in Tables 1 and 2 are for the pipeline gas on the wet basis of 5.4 lb. H2O water per MMSCF supplied by API. All subsequent calculations were performed on this basis. When compressibility factors were calculated for the original analysis supplied by API, converted to a wet basis, the difference from the experimental values was considerably greater than normally found. A careful reanalysis was performed by Cities Service and the agreement became very good, as can be seen from Table 5. From this it can be seen that inaccuracies in composition analysis can result in undesireable errors in calculated compressibilities. The final wet basis composition for the gas is given at the top of Tables 1 and 2.

For sake of completeness, the experimental compressibility factor data for the dry Gulf Coast gas are repeated in Tables 3 and 4, and Figures 3 and 4, Appendix B. The gas composition is given at the top of each table.

COMPUTATION WORK

During discusssion of changing API's chromatographic analysis to a wet basis, it was discovered that a communication error had occurred during the early 1985 work on the Gulf Coast gas. All data and calculations were reported for the cylinder of test gas supplied by API, per the proposal. A Committee member pointed out the need for calculations to be made for the wet flowing gas with an average water content of 4.6 lb H20 per MMSCF. To maintain the quality and utility of our work, O.U. recalculated both the compressibility factor and C* values for the Gulf Coast gas. This work was done without charge to API.

Comparison of the calculated compressibility factors with the experimental values for the wet Amarillo gas is given in Table 5, Appendix C. All deviations are less than 0.1% and most are less than 0.05%. Again the excellence of the OU/GRI correlation was proven.

For completeness, comparison of the calculated and experimental values for the Gulf Coast gas are given in Table 6, Appendix D. This can only be on the dry basis because the gas supplied by API for the test work was dry. This work was done without charge.

The calculated values of the compressibility factor for the pressure and temperature increments agreed upon are presented in Table 7, Appendix E, for the wet Amarillo gas. These values were calculated using the OU/GRI correlation.

The new calculated values of the compressibility factor for the pressure and temperature increments agreed upon are presented in Table 8, Appendix F, for the wet Gulf Coast gas. This work also was performed without charge.

The dew point curve for the wet Amarillo gas is presented in Figure 5, Appendix G. Expansion calculations were performed to determine whether a given set of conditions might result in condensation. To use the figure, select the condition of interest in the column of lettered points to the right. The outlet condition is represented by the same letter in the same row in the left hand column of letters. From the figure, it can be seen that the chance of condensation is very slight for the inlet pressures available. Only the lowest temperatures at the highest pressures should be of concern.

The calculated C* values for the wet Amarillo gas are presented in Table 9, Appendix G. At the end of this Appendix are Tables 9a and 9b, which give mass flow rate comparisons between the OU/GRI correlation result and the Johnson tables for both the Amarillo and Gulf Coast gases.

Similarly, the dew point curve for the wet Gulf Coast gas is shown in Figure 6, Appendix H. The calculated values differ so slightly from those reported earlier that this table is not repeated.

INTERPOLATION TABLES

Given the range of composition, heating value, and gravity supplied by API for the Amarillo gas and Gulf Coast gas, interpolation functions were developed in the following manner.

1). The condition at which the compressibiliity factor and critical flow factor would change most for change in the variable was selected to determine whether gas composition, heating value, or specific gravity would be best for developing interpolation equations. This condition was found to be the lowest temperature, highest pressure condition for the range of the calculations to be made (50 deg. F and 700 psia.). The best variable was found to be the heating value.

2). Compressibility factor and critical flow factor values were calculated using the OU/GRI equation of state for each of the compositions supplied by API and plotted versus pressure for both types of gas. Then Z and C* values were plotted versus heating value to determine the functional form that could be used for interpolation. It was observed for both gases that a nearly linear relationship exists between the heating value of the gas and the critical flow factor and the same for compressibility factor at constant temperature and constant pressure conditions. This relationship holds within the targeted uncertainty.

3). A linear function of pressure and heating value was selected to model the critical flow factor and the compressibility factor for each isotherm. That is, Z = A + B*HV + C*P and C* = K + L*HV + M*P. The variation of C* was noted to be less than the variation of Z for the range of conditions under consideration.

4). Data for Z and C* were generated for interpolation purposes using the OU/GRI equation of state at five (5) heating values for temperatures from 40 to 110 degrees F and pressures from 360 to 740 psia for both the Amarillo gas and the Gulf Coast gas. The range of heating values covered the range supplied by API to insure that the interpolation equations were applicable to all of the gases under consideration. For the Amarillo gas, the heating value ranged from 1024.7 to 1053.2 Btu. The Gulf Coast gas heating values ranged from 10224.1 to 1029.2 Btu.

5). Acceptable results were obtained from the modeling in 3) and 4), i.e., the interpolated values are within 0.1% of the calculated values. Comparison of the interpolated results with the measured values also shows good agreement.

To use the interpolation tables, one only needs to supply the gross heating value of the wet gas using API's method and the operating pressure heating value of the gas using API's method and the operating pressure in psia. The appropriate function(s) to be used are located by the operating temperature condition (deg. F). If calculation is needed for an intermediate temperature, then linear interpolation between the values calculated for the adjacent temperatures may be used. Z and C* relations are provided for each gas for the range of conditions needed lby API. It is important to note that the relationships are not valid outside the range of conditions used to develop them and therefore should not be used beyond the temperature, pressure, and heating value conditions stated above - please do not extrapolate.

The interpolation tables are as follows. Table 10, Appendix I, gives constants for interpolating compressibility factors for Amarillo gas between pressures at constant temperature. Table 11, Appendix I gives constants for interpolating critical flow factors between pressures at constant temperature.

Table 12, Appendix I presents the constants for interpolating compressibility factors for the wet Gulf Coast gas and Table 13 Appendix I gives those for critical flow factors.

CAUTION. The Investigators are not in favor of using this method to obtain intermediate values of Z or C*. The computer programs are available for both and would be recommended for any future work. These tables should be marked and used only for the current work.

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5. Starling, K. E., et al., "Development of an Equation of State for the Computation of Natural Gas Supercompressibility Factor and Other Properties," Operating Section Proceedings of the American Gas Association, (1984).

6. Ellington, R. T., Hill, M. J., and Savidge, J. L.,

Appendix A

Table 1. Compressibility Factors for Amarillo Gas at 288.71 K.

Composition: 90.66 % CH_4 - 4.59 % C_2H_6 - 0.78 % C_3H_8 - 0.14 % n-C_4H_{10} - 0.10 % i-C_4H_{10} - 0.02 % n-C_5H_{12} - 0.03 % i-C_5H_{12} - 0.03 % C_6H_{14} - 3.22 % N_2 - 0.42 % CO_2 - 0.01 % H_2O
A=V2/V1: 50.0271
B (Sec. Vir. Coef.): -0.1532 X 10(-3) 1/psia

T(F)	P1(psia)	P2(psia)	P3(psia)	Z
60.008	913.265	14.110	34.326	0.86695
60.008	913.325	14.076	34.291	0.86712
60.008	913.221	14.066	34.281	0.86703
60.008	913.229	14.068	34.289	0.86673
60.008	863.407	14.216	33.160	0.87395
60.008	863.406	14.215	33.158	0.87398
60.008	863.405	14.209	33.155	0.87383
60.008	813.470	14.228	31.927	0.88057
60.008	813.468	14.228	31.924	0.88074
60.008	813.464	14.222	31.919	0.88065
60.008	763.442	14.159	30.621	0.88774
60.008	763.440	14.159	30.622	0.88767
60.008	713.498	14.164	29.413	0.89463
60.008	713.492	14.162	29.410	0.89467
60.008	713.490	14.161	29.408	0.89473
60.008	663.552	14.172	28.224	0.90169
60.008	663.548	14.168	28.220	0.90172
60.008	613.641	14.228	27.098	0.90887
60.008	613.637	14.224	27.094	0.90891
60.008	613.634	14.219	27.090	0.90885
60.008	563.523	14.040	25.749	0.91593
60.008	563.525	14.044	25.752	0.91606
60.008	563.654	14.051	25.759	0.91626
60.008	513.744	14.233	24.795	0.92323
60.008	513.743	14.235	24.795	0.92339
60.008	513.741	14.232	24.792	0.92338
60.008	513.572	14.039	24.602	0.92317
60.008	463.518	13.925	23.356	0.93080
60.008	463.517	13.923	23.354	0.93081
60.008	463.512	13.920	23.352	0.93072

Table 1 (continued)

60.008	413.747	14.127	22.447	0.93801
60.008	413.746	14.125	22.444	0.93806
60.008	413.746	14.124	22.445	0.93792
60.008	363.623	13.933	21.158	0.94539
60.008	363.618	13.928	21.152	0.94551
60.008	363.612	13.927	21.151	0.94554
60.008	313.843	14.124	20.269	0.95278
60.008	313.843	14.128	20.273	0.95286
60.008	313.844	14.127	20.271	0.95298
60.008	263.735	13.949	19.032	0.96032
60.008	263.730	13.943	19.026	0.96037
60.008	263.723	13.938	19.020	0.96040
60.008	213.878	14.056	18.091	0.96779
60.008	213.873	14.055	18.089	0.96778
60.008	164.074	14.219	17.222	0.97537
60.008	164.050	14.192	17.195	0.97526
60.008	163.987	14.130	17.134	0.97515

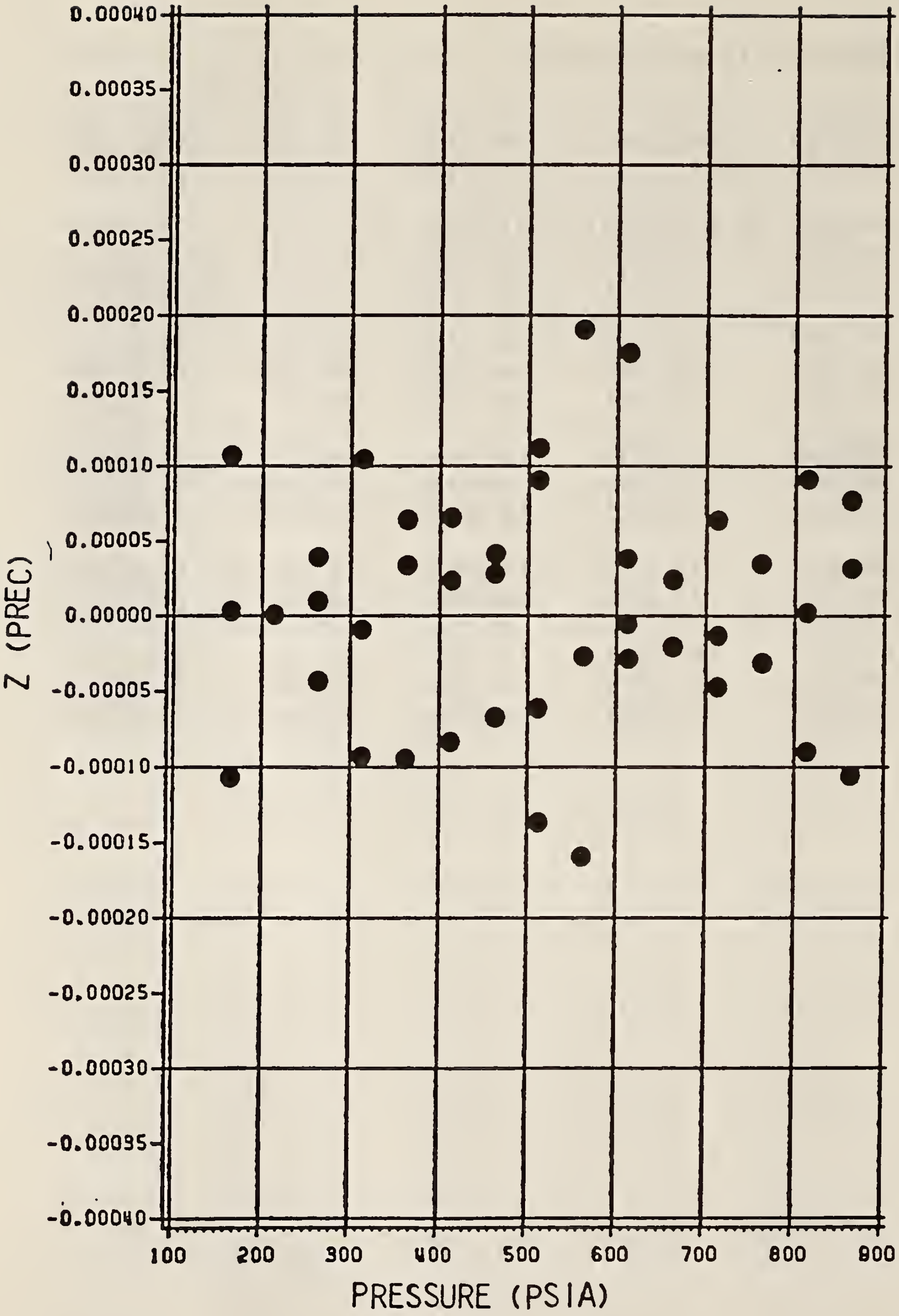


FIGURE 1. Z (PREC) VERSUS PRESSURE (PSIA) FOR AMARILLO GAS AT 288.71 K.

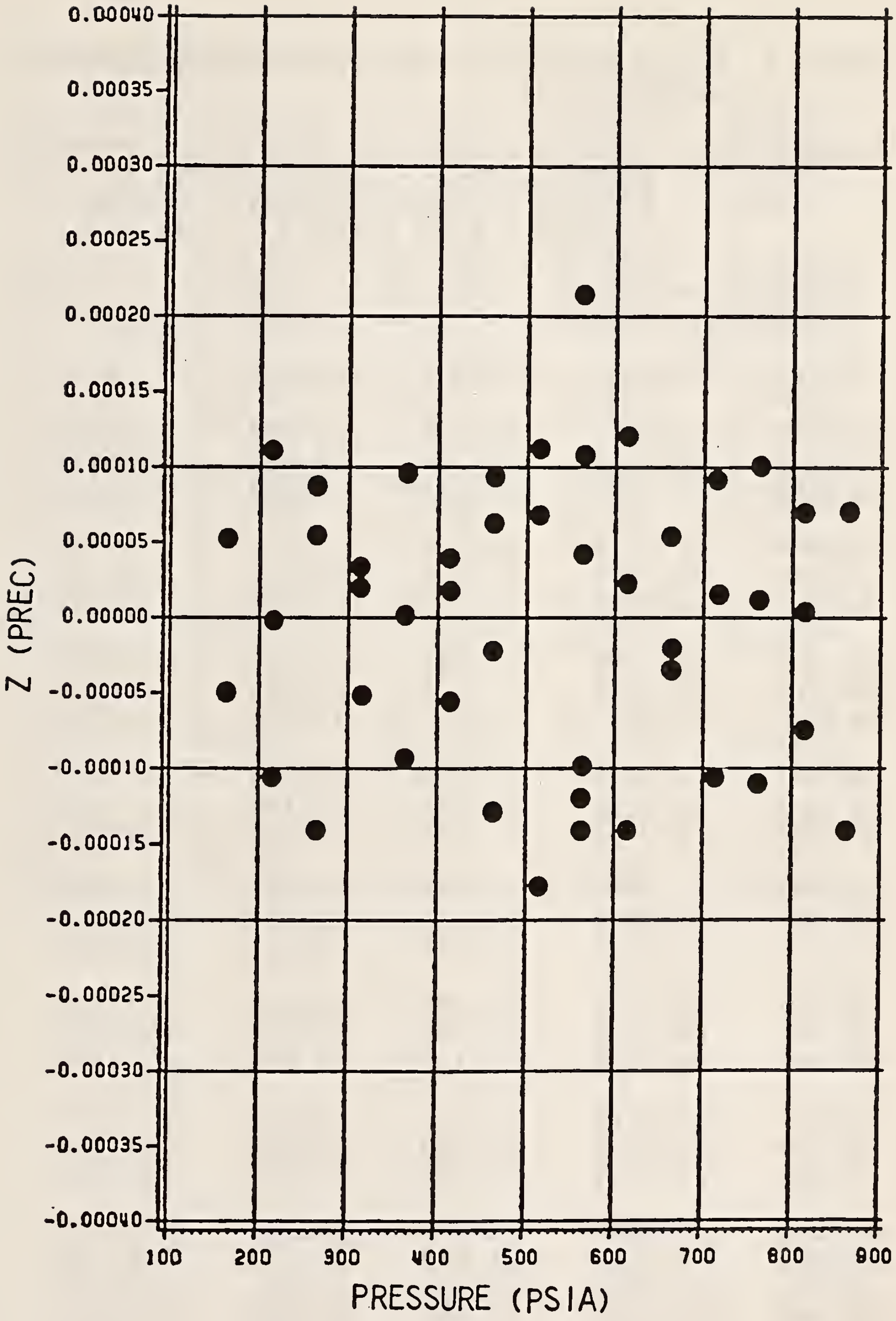


FIGURE 2. Z (PREC) VERSUS PRESSURE (PSIA) FOR AMARILLLO GAS AT 299.85 K.

Table 2. Compressibility Factors for Amarillo Gas at 299.85 K.

Composition: 90.66 % CH4 - 4.59 % C2H6 - 0.78 % C3H8 - 0.14 % n-C4H10 - 0.10 % i-C4H10 - 0.02 % n-C5H12 - 0.03 % i-C5H12 - 0.03 % C6H14 - 3.22 % N2 - 0.42 % CO2 - 0.01 % H2O

A=V2/V1: 49.9518

B (Sec. Vir. Coef.): -0.1334 X 10(-3) 1/psia

T(F)	P1(psia)	P2(psia)	P3(psia)	Z
80.060	913.270	14.136	33.954	0.88631
80.060	913.269	14.130	33.951	0.88616
80.060	913.269	14.134	33.951	0.88634
80.060	863.328	14.140	32.746	0.89173
80.060	863.324	14.140	32.742	0.89192
80.060	863.317	14.133	32.735	0.89192
80.060	813.452	14.231	31.630	0.89767
80.060	813.450	14.225	31.627	0.89754
80.060	813.447	14.222	31.622	0.89761
80.060	763.500	14.234	30.444	0.90339
80.060	763.500	14.235	30.444	0.90350
80.060	763.501	14.237	30.443	0.90358
80.060	713.469	14.142	29.179	0.90914
80.060	713.546	14.230	29.268	0.90903
80.060	713.546	14.233	29.268	0.90921
80.060	663.568	14.200	28.069	0.91546
80.060	663.565	14.195	28.065	0.91538
80.060	663.561	14.190	28.059	0.91539
80.060	613.628	14.211	26.933	0.92133
80.060	613.626	14.209	26.929	0.92148
80.060	613.623	14.208	26.926	0.92157
80.060	563.495	14.017	25.600	0.92779
80.060	563.493	14.017	25.598	0.92789
80.060	563.492	14.014	25.598	0.92773
80.060	563.728	14.270	25.855	0.92760
80.060	563.727	14.268	25.853	0.92758
80.060	563.719	14.260	25.845	0.92756
80.060	513.565	14.040	24.501	0.93403
80.060	513.550	14.021	24.485	0.93376
80.060	513.541	14.016	24.478	0.93399

Table 2 (continued)

80.060	463.650	14.082	23.439	0.93997
80.060	463.623	14.050	23.406	0.94007
80.060	463.617	14.045	23.400	0.94015
80.060	463.823	14.268	23.623	0.94018
80.060	413.917	14.320	22.581	0.94645
80.060	413.906	14.305	22.567	0.94638
80.060	413.898	14.298	22.559	0.94647
80.060	363.982	14.337	21.518	0.95273
80.060	363.976	14.331	21.512	0.95282
80.060	363.972	14.326	21.506	0.95291
80.060	314.034	14.343	20.458	0.95919
80.060	314.033	14.341	20.456	0.95912
80.060	314.031	14.339	20.454	0.95920
80.060	264.083	14.345	19.408	0.96549
80.060	264.083	14.346	19.408	0.96568
80.060	264.083	14.345	19.407	0.96571
80.060	213.920	14.116	18.140	0.97221
80.060	213.913	14.107	18.131	0.97211
80.060	213.904	14.098	18.121	0.97232
80.060	164.014	14.164	17.162	0.97866
80.060	163.980	14.129	17.128	0.97856
80.060	163.974	14.125	17.123	0.97866

Table 3. Compressibility Factors for Gulf Coast Gas at 288.71 K.

Composition: 96.5007 % CH4 - 1.7490 % C2H6 - 0.4003 % C3H8 - 0.0999% n-C4H10 - 0.1000 % i-C4H10 - 0.1001 % n-C5H12 - 0.0999 % i-C5H12 - 0.1001 % C6H14 - 0.2501 % N2 - 0.5990 % CO2
A=V2/V1: 50.0221
B (Sec. Vir. Coef.)= -0.1484 X 10(-3) 1/psia

T(F)	P1(psia)	P2(psia)	P3(psia)	Z
60.008	763.416	14.196	30.606	0.89072
60.008	763.409	14.183	30.591	0.89080
60.008	763.366	14.140	30.542	0.89111
60.008	713.719	14.442	29.642	0.89766
60.008	713.704	14.429	29.624	0.89794
60.008	713.687	14.417	29.610	0.89803
60.008	713.695	14.427	29.626	0.89769
60.008	663.742	14.427	28.436	0.90454
60.008	663.740	14.424	28.428	0.90482
60.008	663.738	14.425	28.435	0.90449
60.008	663.743	14.432	28.440	0.90457
60.008	613.791	14.428	27.263	0.91148
60.008	613.778	14.414	27.246	0.91169
60.008	613.777	14.411	27.245	0.91154
60.008	563.820	14.410	26.087	0.91855
60.008	563.822	14.414	26.089	0.91867
60.008	563.824	14.414	26.092	0.91847
60.008	563.812	14.402	26.081	0.91838
60.008	513.860	14.399	24.938	0.92541
60.008	513.858	14.397	24.932	0.92578
60.008	513.853	14.396	24.933	0.92552
60.008	513.850	14.389	24.928	0.92539
60.008	463.892	14.384	23.797	0.93258
60.008	463.888	14.379	23.790	0.93281
60.008	463.882	14.375	23.785	0.93290
60.008	463.877	14.370	23.782	0.93277
60.008	413.921	14.367	22.671	0.93978
60.008	413.920	14.365	22.668	0.93999
60.008	413.920	14.367	22.671	0.93980
60.008	413.924	14.374	22.677	0.93993
60.008	413.932	14.378	22.683	0.93972

Table 3 (continued)

60.008	363.981	14.381	21.595	0.94681
60.008	363.983	14.383	21.593	0.94716
60.008	363.987	14.385	21.597	0.94698
60.008	363.988	14.389	21.601	0.94696
60.008	314.037	14.390	20.526	0.95417
60.008	314.037	14.387	20.524	0.95411
60.008	314.030	14.378	20.514	0.95429
60.008	314.026	14.374	20.510	0.95415
60.008	264.067	14.368	19.445	0.96112
60.008	264.065	14.364	19.439	0.96154
60.008	264.061	14.361	19.436	0.96139
60.008	264.056	14.357	19.432	0.96144
60.008	214.102	14.355	18.386	0.96858
60.008	214.101	14.354	18.384	0.96867
60.008	214.101	14.351	18.383	0.96833
60.008	214.097	14.350	18.381	0.96859
60.008	164.144	14.349	17.350	0.97570
60.008	164.143	14.349	17.350	0.97573
60.008	164.144	14.349	17.350	0.97575
60.008	114.192	14.350	16.336	0.98299
60.008	114.192	14.351	16.336	0.98309
60.008	114.192	14.351	16.337	0.98301
60.008	114.194	14.353	16.339	0.98308
60.008	114.193	14.351	16.337	0.98324
60.008	114.191	14.348	16.334	0.98315

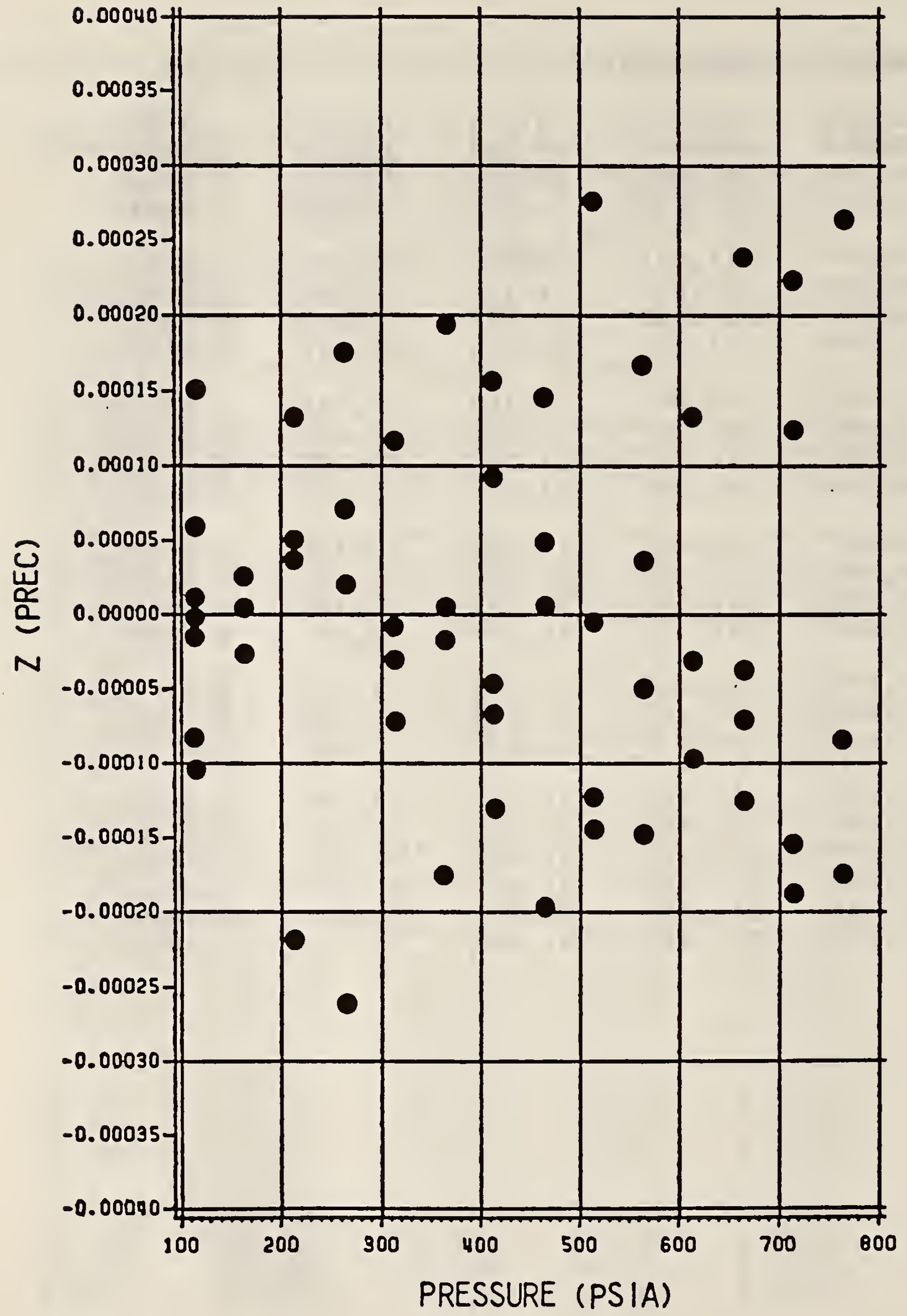


FIGURE 3. Z (PREC) VERSUS PRESSURE (PSIA) FOR GULF COAST GAS AT 288.71 K.

Appendix B

Table 4. Compressibility Factors for Gulf Coast Gas at at 299.85 K.

Composition: 96.5007 % CH4 - 1.7490 % C2H6 - 0.4003
% C3H8 - 0.0999% n-C4H10 - 0.1000 %
i-C4H10 - 0.1001 % n-C5H12 - 0.0999 %
i-C5H12 - 0.1001 % C6H14 - 0.2501 %
N2 - 0.5990 % CO2
A=V2/V1: 49.9162
B (Sec. Vir. Coef.): -0.1284 X 10(-3) 1/psia

T(F)	P1(psia)	P2(psia)	P3(psia)	Z
80.060	763.529	14.303	30.472	0.90644
80.060	763.529	14.307	30.475	0.90649
80.060	763.523	14.305	30.472	0.90650
80.060	713.566	14.293	29.291	0.91223
80.060	713.537	14.264	29.261	0.91226
80.060	713.520	14.247	29.245	0.91222
80.060	663.416	14.087	27.925	0.91818
80.060	663.414	14.084	27.923	0.91813
80.060	663.408	14.082	27.921	0.91817
80.060	613.487	14.108	26.805	0.92391
80.060	613.479	14.102	26.797	0.92402
80.060	613.474	14.097	26.790	0.92416
80.060	613.468	14.092	26.786	0.92410
80.060	563.554	14.130	25.696	0.92986
80.060	563.554	14.132	25.696	0.92997
80.060	563.541	14.116	25.683	0.92981
80.060	513.613	14.139	24.588	0.93581
80.060	513.613	14.147	24.593	0.93609
80.060	513.617	14.151	24.595	0.93619
80.060	513.612	14.143	24.589	0.93604
80.060	513.607	14.139	24.585	0.93605
80.060	463.741	14.230	23.572	0.94210
80.060	463.741	14.230	23.572	0.94212
80.060	413.745	14.178	22.432	0.94798
80.060	413.808	14.178	22.432	0.94812
80.060	413.739	14.175	22.428	0.94809
80.060	413.828	14.273	22.527	0.94796
80.060	413.809	14.231	22.485	0.94802
80.060	363.945	14.344	21.521	0.95414
80.060	363.949	14.348	21.523	0.95426
80.060	363.953	14.355	21.531	0.95412

Table 4 (continued)

80.060	313.939	14.288	20.399	0.96038
80.060	313.945	14.296	20.407	0.96055
80.060	313.949	14.302	20.413	0.96053
80.060	313.978	14.330	20.443	0.96026
80.060	263.935	14.231	19.291	0.96689
80.060	263.930	14.230	19.290	0.96681
80.060	263.932	14.233	19.293	0.96689
80.060	213.995	14.244	18.266	0.97304
80.060	213.992	14.239	18.261	0.97309
80.060	213.988	14.236	18.259	0.97303
80.060	164.035	14.237	17.234	0.97930
80.060	164.034	14.241	17.239	0.97923
80.060	164.040	14.252	17.250	0.97937

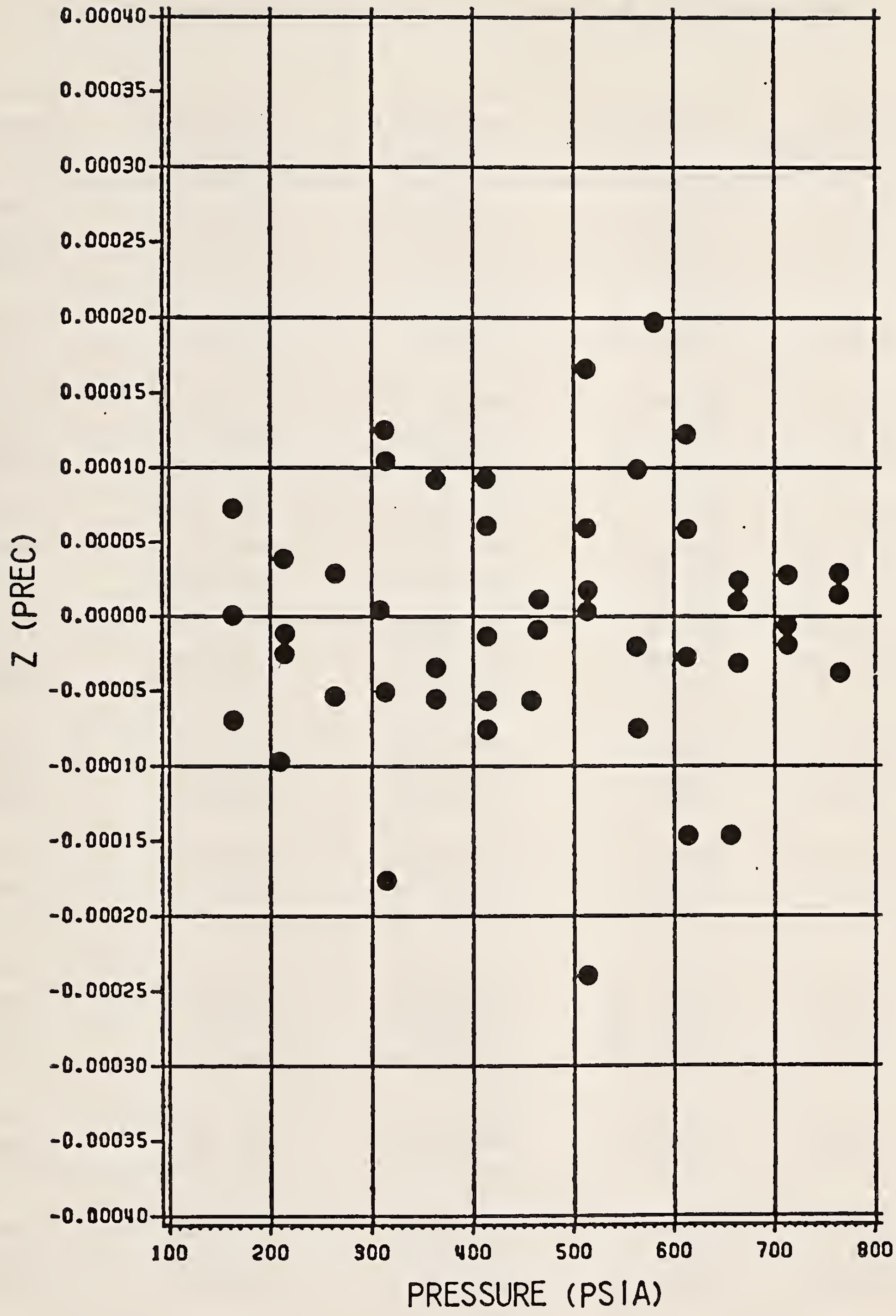


FIGURE 4 Z (PREC) VERSUS PRESSURE (PSIA) FOR GULF COAST GAS AT 299.85 K.

Appendix C

Comparison of Calculated and Experimental Compressibility Factors, Z, - Wet Amarillo Gas

Table 5

Comparison of Calculated and Experimental Compressibility Factors, Z, - Wet Amarillo Gas

Temperature F	Pressure psia	Z-factor exp.	Z-factor calc.	Percent deviation
60.008	163.987	0.97515	0.97542	-0.027
60.008	164.050	0.97526	0.97541	-0.015
60.008	164.075	0.97537	0.97540	-0.004
60.008	213.874	0.96778	0.96796	-0.019
60.008	213.879	0.96779	0.96796	-0.018
60.008	263.724	0.96040	0.96053	-0.014
60.008	263.731	0.96037	0.96053	-0.017
60.008	263.736	0.96032	0.96053	-0.022
60.008	313.844	0.95278	0.95308	-0.031
60.008	313.844	0.95286	0.95308	-0.023
60.008	313.845	0.95298	0.95308	-0.010
60.008	363.613	0.94554	0.94570	-0.017
60.008	363.619	0.94551	0.94570	-0.020
60.008	363.624	0.94539	0.94570	-0.033
60.008	413.747	0.93806	0.93830	-0.026
60.008	413.747	0.93792	0.93830	-0.041
60.008	413.748	0.93801	0.93830	-0.031
60.008	463.513	0.93072	0.93100	-0.030
60.008	463.518	0.93081	0.93099	-0.020
60.008	463.519	0.93080	0.93099	-0.021
60.008	513.574	0.92317	0.92368	-0.056
60.008	513.743	0.92338	0.92366	-0.030
60.008	513.745	0.92339	0.92366	-0.029
60.008	513.746	0.92323	0.92366	-0.046
60.008	563.525	0.91593	0.91643	-0.055
60.008	563.527	0.91606	0.91643	-0.041
60.008	563.656	0.91626	0.91641	-0.017
60.008	613.636	0.90885	0.90921	-0.040
60.008	613.639	0.90891	0.90921	-0.033
60.008	613.643	0.90887	0.90921	-0.038
60.008	663.550	0.90172	0.90208	-0.040
60.008	663.554	0.90169	0.90208	-0.043

Table 5

60.008	713.492	0.89473	0.89501	-0.032
60.008	713.494	0.89467	0.89501	-0.038
60.008	713.500	0.89463	0.89501	-0.043
60.008	763.443	0.88767	0.88802	-0.039
60.008	763.445	0.88774	0.88802	-0.032
60.008	813.467	0.88065	0.88110	-0.051
60.008	813.471	0.88074	0.88110	-0.041
60.008	813.473	0.88057	0.88110	-0.060
60.008	863.408	0.87383	0.87428	-0.052
60.008	863.409	0.87398	0.87428	-0.035
60.008	863.410	0.87395	0.87428	-0.038
60.008	913.224	0.86703	0.86758	-0.064
60.008	913.232	0.86673	0.86758	-0.098
60.008	913.268	0.86695	0.86758	-0.072
60.008	913.328	0.86712	0.86757	-0.052
80.060	163.974	0.97866	0.97859	0.007
80.060	163.981	0.97856	0.97859	-0.003
80.060	164.014	0.97866	0.97859	0.007
80.060	213.905	0.97232	0.97213	0.020
80.060	213.914	0.97211	0.97212	-0.002
80.060	213.921	0.97221	0.97212	0.009
80.060	264.084	0.96549	0.96566	-0.017
80.060	264.084	0.96568	0.96566	0.002
80.060	264.084	0.96571	0.96566	0.006
80.060	314.032	0.95920	0.95925	-0.005
80.060	314.034	0.95912	0.95925	-0.013
80.060	314.035	0.95919	0.95925	-0.006
80.060	363.973	0.95291	0.95288	0.003
80.060	363.977	0.95282	0.95288	-0.006
80.060	363.983	0.95273	0.95288	-0.015
80.060	413.899	0.94647	0.94655	-0.008
80.060	413.907	0.94638	0.94655	-0.018
80.060	413.918	0.94645	0.94655	-0.010
80.060	463.619	0.94015	0.94029	-0.015
80.060	463.624	0.94007	0.94029	-0.024
80.060	463.651	0.93997	0.94029	-0.034
80.060	463.824	0.94018	0.94027	-0.009
80.060	513.543	0.93399	0.93406	-0.007
80.060	513.551	0.93376	0.93406	-0.032
80.060	513.566	0.93403	0.93406	-0.003

Table 5

80.060	563.494	0.92773	0.92788	-0.016
80.060	563.495	0.92789	0.92788	0.001
80.060	563.497	0.92779	0.92788	-0.009
80.060	563.721	0.92756	0.92785	-0.031
80.060	563.729	0.92758	0.92785	-0.029
80.060	563.730	0.92760	0.92785	-0.027
80.060	613.625	0.92157	0.92173	-0.018
80.060	613.628	0.92148	0.92173	-0.027
80.060	613.630	0.92133	0.92173	-0.044
80.060	663.563	0.91539	0.91568	-0.031
80.060	663.567	0.91538	0.91568	-0.032
80.060	663.570	0.91546	0.91568	-0.024
80.060	713.471	0.90914	0.90970	-0.061
80.060	713.548	0.90903	0.90969	-0.072
80.060	713.548	0.90921	0.90969	-0.052
80.060	763.502	0.90339	0.90378	-0.043
80.060	763.502	0.90350	0.90378	-0.031
80.060	763.504	0.90358	0.90378	-0.022
80.060	813.450	0.89761	0.89795	-0.038
80.060	813.453	0.89754	0.89795	-0.046
80.060	813.455	0.89767	0.89795	-0.031
80.060	863.320	0.89192	0.89222	-0.034
80.060	863.327	0.89192	0.89222	-0.034
80.060	863.331	0.89173	0.89222	-0.055
80.060	913.272	0.88616	0.88659	-0.048
80.060	913.272	0.88634	0.88659	-0.028
80.060	913.273	0.88631	0.88659	-0.031

Appendix D

Table 6

Comparison of Calculated and Experimental Compressibility Factors, Z, - Dry Gulf Coast Gas

Temperature F	Pressure psia	Z-factor exp.	Z-factor calc.	Percent deviation
60.008	114.191	0.98315	0.98336	-0.021
60.008	114.192	0.98299	0.98336	-0.037
60.008	114.192	0.98309	0.98336	-0.027
60.008	114.192	0.98301	0.98336	-0.035
60.008	114.193	0.98324	0.98336	-0.012
60.008	114.194	0.98308	0.98336	-0.028
60.008	164.144	0.97573	0.97609	-0.037
60.008	164.144	0.97570	0.97609	-0.040
60.008	164.144	0.97575	0.97609	-0.035
60.008	214.098	0.96859	0.96884	-0.026
60.008	214.102	0.96867	0.96884	-0.018
60.008	214.102	0.96833	0.96884	-0.053
60.008	214.103	0.96858	0.96884	-0.027
60.008	264.057	0.96144	0.96161	-0.018
60.008	264.062	0.96139	0.96161	-0.023
60.008	264.066	0.96154	0.96161	-0.007
60.008	264.068	0.96112	0.96161	-0.051
60.008	314.027	0.95415	0.95440	-0.026
60.008	314.031	0.95429	0.95440	-0.011
60.008	314.038	0.95417	0.95440	-0.024
60.008	314.038	0.95411	0.95440	-0.030
60.008	363.982	0.94681	0.94721	-0.043
60.008	363.984	0.94716	0.94721	-0.006
60.008	363.988	0.94698	0.94721	-0.025
60.008	363.989	0.94696	0.94721	-0.027
60.008	413.921	0.93999	0.94006	-0.008
60.008	413.921	0.93980	0.94006	-0.028
60.008	413.922	0.93978	0.94006	-0.030
60.008	413.925	0.93993	0.94006	-0.014
60.008	413.933	0.93972	0.94006	-0.036
60.008	463.878	0.93277	0.93294	-0.019
60.008	463.883	0.93290	0.93294	-0.005
60.008	463.890	0.93281	0.93294	-0.014
60.008	463.893	0.93258	0.93294	-0.039
60.008	513.852	0.92539	0.92586	-0.051
60.008	513.855	0.92552	0.92586	-0.037
60.008	513.859	0.92578	0.92586	-0.009
60.008	513.862	0.92541	0.92586	-0.049

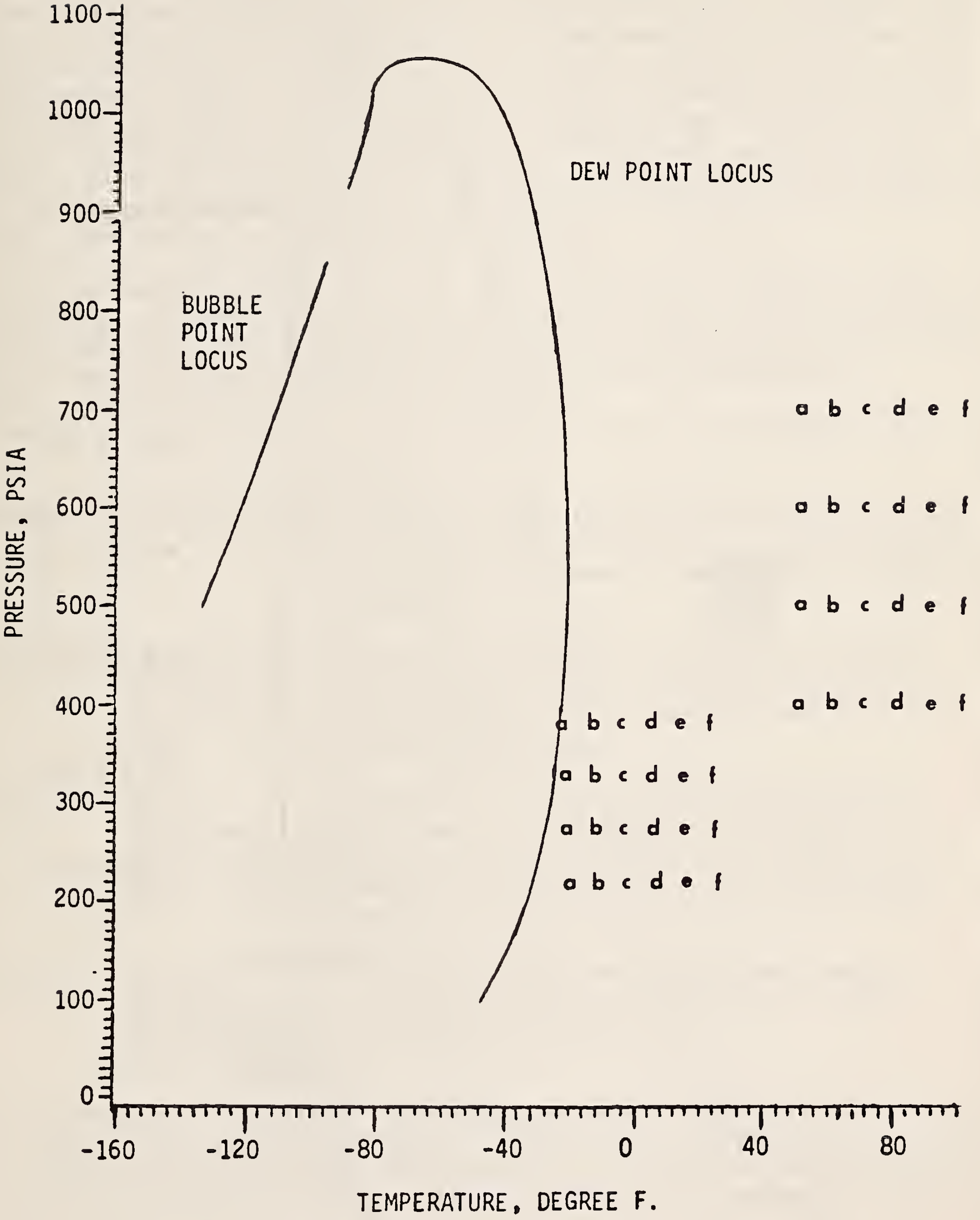
60.008	563.814	0.91838	0.91883	-0.049
60.008	563.822	0.91855	0.91883	-0.030
60.008	563.824	0.91867	0.91883	-0.017
60.008	563.826	0.91847	0.91883	-0.039
60.008	613.779	0.91154	0.91185	-0.034
60.008	613.780	0.91169	0.91185	-0.017
60.008	613.793	0.91148	0.91185	-0.040
60.008	663.740	0.90449	0.90493	-0.048
60.008	663.742	0.90482	0.90493	-0.012
60.008	663.744	0.90454	0.90493	-0.043
60.008	663.745	0.90457	0.90493	-0.039
60.008	713.689	0.89803	0.89807	-0.005
60.008	713.697	0.89769	0.89807	-0.042
60.008	713.706	0.89794	0.89807	-0.014
60.008	713.721	0.89766	0.89807	-0.045
60.008	763.368	0.89111	0.89132	-0.024
60.008	763.411	0.89080	0.89132	-0.058
60.008	763.419	0.89072	0.89132	-0.067
80.060	164.034	0.97923	0.97919	0.004
80.060	164.035	0.97930	0.97919	0.011
80.060	164.040	0.97937	0.97919	0.018
80.060	213.989	0.97303	0.97291	0.012
80.060	213.993	0.97309	0.97291	0.019
80.060	213.996	0.97304	0.97291	0.013
80.060	263.931	0.96681	0.96666	0.016
80.060	263.933	0.96689	0.96666	0.024
80.060	263.936	0.96689	0.96666	0.024
80.060	313.940	0.96038	0.96043	-0.005
80.060	313.946	0.96055	0.96043	0.013
80.060	313.950	0.96053	0.96043	0.011
80.060	313.979	0.96026	0.96042	-0.017
80.060	363.946	0.95414	0.95423	-0.010
80.060	363.950	0.95426	0.95423	0.003
80.060	363.954	0.95412	0.95423	-0.012
80.060	413.740	0.94809	0.94811	-0.002
80.060	413.746	0.94798	0.94811	-0.014
80.060	413.809	0.94812	0.94810	0.002
80.060	413.810	0.94802	0.94810	-0.009
80.060	413.829	0.94796	0.94810	-0.015
80.060	463.742	0.94210	0.94200	0.010
80.060	463.742	0.94212	0.94200	0.012
80.060	513.609	0.93605	0.93596	0.009
80.060	513.613	0.93604	0.93596	0.008
80.060	513.615	0.93581	0.93596	-0.016
80.060	513.615	0.93609	0.93596	0.014
80.060	513.619	0.93619	0.93596	0.024

80.060	563.543	0.92981	0.92997	-0.017
80.060	563.556	0.92986	0.92996	-0.011
80.060	563.556	0.92997	0.92996	0.001
80.060	613.470	0.92410	0.92403	0.008
80.060	613.476	0.92416	0.92403	0.014
80.060	613.481	0.92402	0.92403	-0.001
80.060	613.489	0.92391	0.92403	-0.013
80.060	663.410	0.91817	0.91815	0.002
80.060	663.416	0.91813	0.91815	-0.003
80.060	663.418	0.91818	0.91815	0.003
80.060	713.522	0.91222	0.91233	-0.012
80.060	713.539	0.91226	0.91232	-0.007
80.060	713.568	0.91223	0.91232	-0.010
80.060	763.525	0.90650	0.90659	-0.010
80.060	763.531	0.90644	0.90659	-0.016
80.060	763.531	0.90649	0.90659	-0.011

Appendix G
Figure 5

PRESSURE - TEMPERATURE DIAGRAM

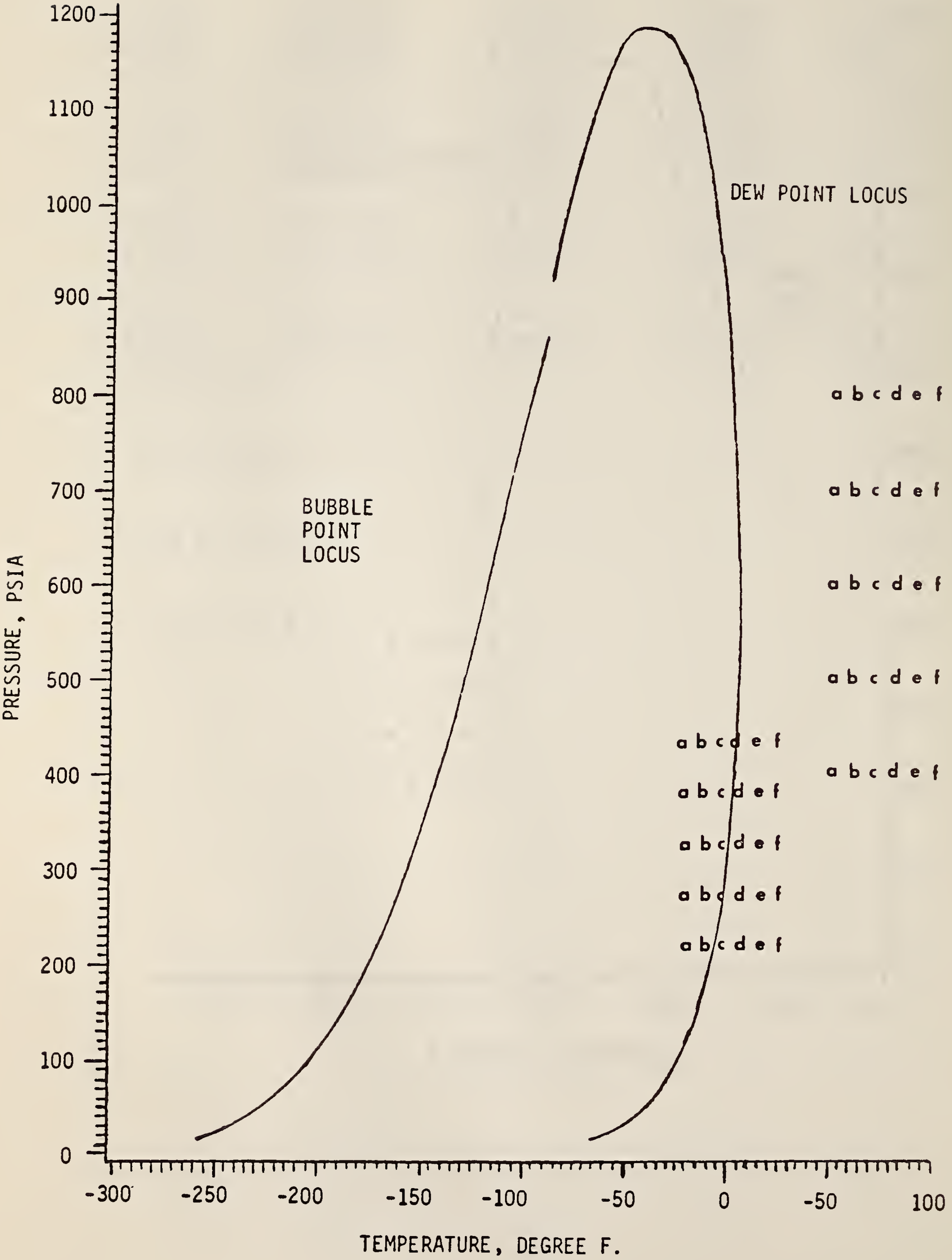
AMARILLO NATURAL GAS



Appendix H
Figure 6

PRESSURE - TEMPERATURE DIAGRAM

GULF COAST NATURAL GAS



Appendix E

Database Structure

Several databases were needed to store the test run data. The following tables give the structures of these. Each record of a database contained a maximum of 32 fields. Due to the number of individual data items necessary for each test run or group of test runs, several databases were used to record the data. The following gives a short description of each type of database and a listing of its structure. Structural information is composed of a field name and type, an indicator of either numeric (N) or character (C) type, and the width of the field given in the number of characters in the field. For numeric fields a decimal point position is included.

Each day's data was contained in a set of databases. The file names of the database set of a day always contained the year and day of the date of the test run. For example for test run data taken on July 30, 1985, each of the following file names were used for the database set.

0730HEAD	Header file	This file contained one record per test run.
0730PRES	Pressure file	This file contained one record for each set of observations taken by the datalogger. One set was taken approxi-mately every 2 seconds.
0730DELP	Differential Pressure Calibration file	This file contained the response values for the differential pressure transducers and standard. One record for each calibration point.
0730STAT	Static Pressure Calibration file	This file contained the response values for the static pressure transducers and weight designation of the deadweight tester. One record for each calibration point.
0730COEF	Pressure Transducer Calibration Coefficients	This file contained the response model coefficients for each transducer. One record per transducer.

Field names were selected to be descriptive of the parameter stored in each field, e.g., the field NOZZL:1 in the header database is a character string with the nozzle designation. If only one nozzle were in operation in the test run then OFF was stored in the appropriate fields.

These databases were used to maintain the complete database for the data acquisition and analysis procedures. It does not reflect the structure or ordering of the archival database which is given in another appendix to this report.

Header Database Structure

```
FLD        NAME       TYPE WIDTH   DEC
001     RUN:NUMBER     N    004
002     NUM:PR:REC     N    004
003     DATE           C    008
004     TIME           C    008
005     NOZZL:1        C    020
006     NOZZL:2        C    020
007     NOZZL:3        C    020
008     NOZZL:4        C    020
009     METR:TUBE      C    020
010     ORF:PLATE      C    020
011     P:BARO         C    012
012     TR0:ZERO       N    012    010
013     TR1:ZERO       N    012    010
014     TR2:ZERO       N    012    010
015     TR3:ZERO       N    012    010
** TOTAL **               00205
```

Chromatograph Database Structure

```
STRUCTURE FOR FILE:  D:0730NCAL.DBF
NUMBER OF RECORDS:   00009
FLD        NAME       TYPE WIDTH   DEC
001     DATE           C    008
002     RUN:TIME       C    008
003     ANL:TIME       C    008
004     MODE           C    004
005     ALARM          C    020
006     C6:PLUS        C    020
007     NITROGEN       C    020
008     METHANE        C    020
009     CO2            C    020
010     ETHANE         C    020
011     PROPANE        C    020
012     I:BUTANE       C    020
013     N:BUTANE       C    020
014     I:PENTANE      C    020
015     N:PENTANE      C    020
** TOTAL **               00249
```

Pressure Database Structure

```
STRUCTURE FOR FILE:  D:0730PRES.DBF
NUMBER OF RECORDS:   01200
FLD        NAME       TYPE WIDTH   DEC
001      RUN:NUMBER   N     004
002      DATE         C     008
003      TIME         C     008
004      CH0:PRES     C     012
005      CH1:PRES     C     012
006      CH2:PRES     C     012
007      CH3:PRES     C     012
008      CH4:PRES     C     012
009      CH5:PRES     C     012
010      CH6:PRES     C     012
011      CH7:PRES     C     012
012      CH8:PRES     C     012
013      CH9:PRES     C     012
014      CH10:PRES    C     012
015      CH11:PRES    C     012
016      CH12:PRES    C     012
017      PRT1:FOR     C     012
018      PRT2:FOR     C     012
019      PRT3:FOR     C     012
020      PRT4:FOR     C     012
021      PRT5:FOR     C     012
022      PRT1:REV     C     012
023      PRT2:REV     C     012
024      PRT3:REV     C     012
025      PRT4:REV     C     012
026      PRT5:REV     C     012
027      PRTCKFOR     C     012
028      PRTCKREV     C     012
** TOTAL **               00321
```

Differential Pressure Calibration Database Structure

```
STRUCTURE FOR FILE:  D:0730DELP.DBF
NUMBER OF RECORDS:   00105
FLD        NAME       TYPE WIDTH   DEC
001      RUN:NUMBER   N     004
002      DATE         C     008
003      TIME         C     008
004      DDR:ZERO     C     012
005      DDR:PRES     C     012
006      SER:NUM1     C     012
007      VOLTAGE1     C     012
008      SER:NUM2     C     012
009      VOLTAGE2     C     012
** TOTAL **               00093
```

Static Pressure Calibration Database Structure

```
STRUCTURE FOR FILE:  D:0730STAT.DBF
NUMBER OF RECORDS:   00008
FLD        NAME      TYPE WIDTH   DEC
001     RUN:NUMBER    N    004
002     DATE          C    008
003     TIME          C    008
004     ATM:PRES      C    012
005     DWT:SER:N     C    012
006     DWT:TEMP      C    012
007     DWT:CAR:WT    C    012
008     DWT:TOT:WT    C    012
009     DWT:ST:PRS    C    012
010     SER:NUM1      C    012
011     VOLTAGE1      C    012
012     SER:NUM2      C    012
013     VOLTAGE2      C    012
014     SER:NUM3      C    012
015     VOLTAGE3      C    012
016     SER:NUM4      C    012
017     VOLTAGE4      C    012
018     SER:NUM5      C    012
019     VOLTAGE5      C    012
020     P:BARO        C    012
** TOTAL **              00225
```

Pressure Transducer Response Model Coefficient Database Structure

```
STRUCTURE FOR FILE:  D:0730COEF.DBF
NUMBER OF RECORDS:   00018
DATE OF LAST UPDATE: 07/06/88
PRIMARY USE DATABASE
FLD        NAME      TYPE WIDTH   DEC
001     SER:NUM       C    012
002     DATE          C    008
003     TIME          C    008
004     COEF:CONS     C    012
005     COEF:LIN      C    012
006     COEF:QUAD     C    012
007     COEF:CUB      C    012
008     STD:DEV       C    012
009     CAL:PRES      N    012    003
** TOTAL **              00101
```

APPENDIX F

Report of Calibration of the 0.125-inch Diameter Nozzle

The report of calibration reproduced here was performed by Colorado Engineering Experiment Station for one of the nozzles used in the testing program. It is reproduced here in keeping with the intent of NBS and API to document this orifice test program as completely as practicable. No alterations have been made to the report with the exception of placing page numbers on each page to conform with the page number system of this report.

CEESI

COLORADO ENGINEERING
EXPERIMENT STATION INC.

LABORATORY/OFFICE
54043 County Rd 37
P.O. Box 41
Nunn, Colo. 80648
303-897-2711

November 24, 1986

Mr. Wayne Fling, Jr.
OXY Oil & Gas Corp.
Post Office Box 300
Tulsa, OK 74102

Dear Wayne:

Enclosed is the calibration information on the second (latest manufacture) 1/8 inch NGPL critical flow venturi.

The following information was given by telephone to Charlie Sindt on September 18, 1984:

Throat Diameter: 0.125 inches
A Coefficient: 0.982698
B Coefficient: 8.29

All my calibration reports show a throat diameter of 0.125 inches and I have no idea where the diameter in the NBS report (0.1248 inches) came from. These three numbers listed above must be used together to provide a complete, accurate use of the calibration. If I can be of further help please let me know.

Yours truly,

Walt

Walt Seidl

enc

cc Dr. James Whetstone, NBS ✓
Mr. Charles Sindt, NBS

CEESI

LABORATORY/OFFICE:
54043 County Rd. 37
P.O Box 41
Nunn, Colo. 80648
303-897-2711

COLORADO ENGINEERING EXPERIMENT STATION INC.

```
CALIBRATIØN ØF A SØNIC NØZZLE
THRØAT  .125 INCHES (NØMINAL)
FØR: NBS  ØRDER: VERBAL C. SINDT
DATA FILE: 84NBS39  DATE: 17 AUG 1984
INLET DIA: 1.66 INCHES   THRØAT DIA: 0.125 INCHES
TEST GAS: AIR   STD DENSITY= 0.074916  LBM/CU-FT
  AT STANDARD CØNDITIØNS ØF 529.69  DEG R, AND 14.696  PSIA
K FACTØR: DISCHARGE CØEFFICIENT
PSIA: INLET STATIC PRESSURE IN PSIA
DEG R: INLET TEMPERATURE IN DEGREES RANKINE
REY NØ: THRØAT REYNØLDS NUMBER

 L   PSIA     DEG R        K FACTØR   REY NØ      LBM/SEC
 1   905.75   537          0.98792    2554700.    0.25816
 2   855.96   534.1        0.98793    2429000.    0.24444
 3   806.1    534.1        0.98848    2285800.    0.23002
 4   756.62   533.5        0.98861    2146200.    0.21579
 5   715.38   532.9        0.98848    2029700.    0.2039
 6   657.06   530.7        0.9887     1872100.    0.18747
 7   607.33   531          0.98871    1726800.    0.17299
 8   508.19   528.9        0.98885    1448700.    0.14469
 9   408.97   531.3        0.98931    1156200.    0.11588
 10  310.2    529          0.98987    880040.     0.087907
 11  115.66   531          0.99065    324980.     0.032557
 12  166.5    532.1        0.9922     467980.     0.046959
 13  214.31   535.4        0.99252    598560.     0.060348
 14  263.43   533.2        0.99072    739360.     0.074307
 15  361.9    533.3        0.98905    1016500.    0.10218

AVERAGE VALUES FØR ABØVE RESULTS:
P= 510.22  PSIA     DENSITY= 2.6102  LBM/CU-FT
T= 532.49  DEG R    VISCØSITY= 1.0227E-6  LBM/INCH-SEC
Z= 0.99162  CØMPRESSIBILITY FACTØR
C* CRIT=  0.53937  LBM-(DEG R)↑0.5/LB-SEC
```

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EXPERIMENT STATION INC.

```
CALIBRATION OF A SONIC FLOW NOZZLE
THROAT: .125 INCHES (NOMINAL)
FOR: N.B.S.  ORDER: VERBAL C. SINDT
DATA FILE: 84NBS37  DATE: 16 AUGUST 1984
INLET DIA: 1.66 INCHES   THROAT DIA: 0.125 INCHES
TEST GAS: AIR   STD DENSITY= 0.074916  LBM/CU-FT
  AT STANDARD CONDITIONS OF 529.69  DEG R, AND 14.696  PSIA
K FACTOR: DISCHARGE COEFFICIENT
PSIA: INLET STATIC PRESSURE IN PSIA
DEG R: INLET TEMPERATURE IN DEGREES RANKINE
REY NO: THROAT REYNOLDS NUMBER

 L   PSIA     DEG R       K FACTOR   REY NO       LBM/SEC
 1   905.76   534.7       0.98695    2567200.     0.25857
 2   855.97   532.7       0.98794    2437700.     0.24482
 3   806.11   531.7       0.98793    2298500.     0.2305
 4   756.63   531.5       0.98821    2156200.     0.21617
 5   715.39   530.5       0.98864    2042500.     0.20447
 6   657.08   529         0.98861    1880100.     0.1878
 7   607.35   529.1       0.9893     1736100.     0.17344
 8   558.02   530.7       0.98934    1586600.     0.15888
 9   508.21   528.6       0.98943    1450700.     0.14483
 10  458.56   527.8       0.98957    1309900.     0.13062
 11  408.98   527.6       0.99004    1167800.     0.11641
 12  359.41   527.2       0.98962    1025400.     0.10216
 13  310.22   527.8       0.98962    882470.      0.087996
 14  260.11   527.5       0.99058    740130.      0.073769
 15  210.58   525.2       0.99225    602770.      0.059876

AVERAGE VALUES FOR ABOVE RESULTS:
P= 558.56  PSIA     DENSITY= 2.8732  LBM/CU-FT
T= 529.43  DEG R    VISCOSITY= 1.0181E-6  LBM/INCH-SEC
Z= 0.99035  COMPRESSIBILITY FACTOR
C* CRIT=  0.54025  LBM-(DEG R)^0.5/LB-SEC
```

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```
84A15  16 AUGUST 1984  NBS NØZZLE  .125 THRØAT

 I   TCAL2   TCAL4   TCAL5   AVG T   PCAL      MASS     %DEV
 1   XXXXX   72.88   73.01   72.94   1632.57   2542.3   -0.001
 2   XXXXX   72.87   73      72.93   1632.56   2542.33   0.001

M1(AVE)= 2542.32    M1(CØRR)=  2545.28


 I   TCAL2   TCAL4   TCAL5   AVG T   PCAL      MASS     %DEV
 1   XXXXX   71.55   71.76   71.65   823.893   1290.31  -0.001
 2   XXXXX   71.55   71.77   71.66   823.934   1290.35   0.001

M2(AVE)= 1290.33    M2(CØRR)=  1291.87

TIMERS: 1 = 6132.03    2 = 6132.11    3 = 6132.    4 = 6132.

TIME:  6132.04  SECØNDS    MASS FLØW RATE:  0.204403  PØUNDS/SECØND

BARØMETRIC PRESSURE:  12.17  PSIA
---------------------------------------------------------------------

NØZZLE:  0.125     THRØAT DIAMETER:  0.125  INCHES

P START= 703.395   P STØP= 703.395
P MIN= 703.395     P MAX= 703.395    P AVE= 703.395  715.565  PSIA

T START= 74.4   T STØP= 70.3
T MIN=   70.3   T MAX=  74.4   T AVE= 71.5717 DEG F     531.262 DEG R

MASS FLØW RATE:  0.20433  PØUNDS PER SECØND

Z= 0.9882   V0= 1.02E-6   C0= 0.5426   R= 2039520.   C= 0.98854
```

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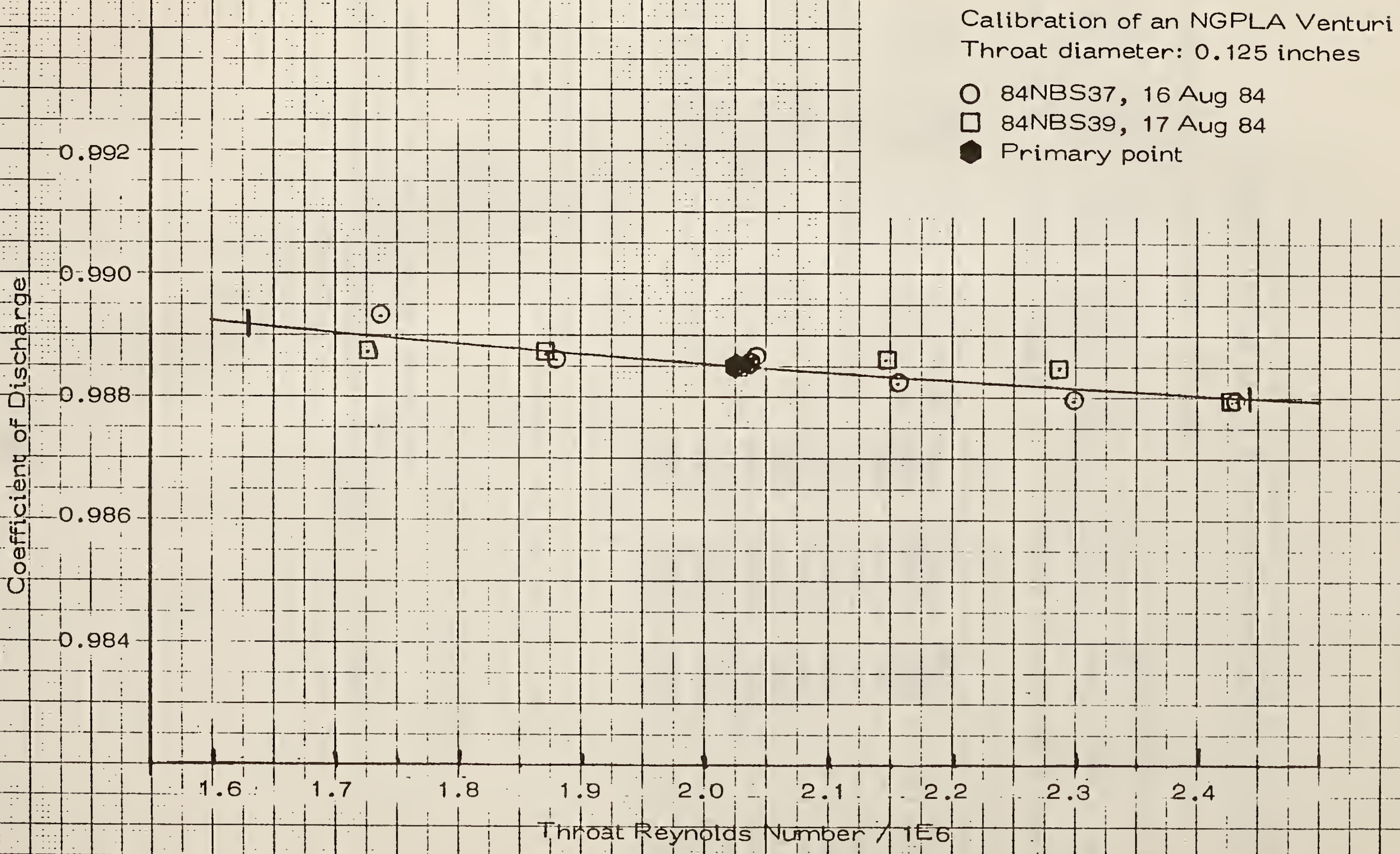
```
84A16  NBS NØZZLE  17 AUG 1984  .125 THRØAT

 I   TCAL2   TCAL4   TCAL5   AVG T   PCAL      MASS      %DEV
 1   XXXXX   75.41   75.69   75.55   1579.19   2445.93   0
 2   XXXXX   75.3    75.57   75.44   1578.81   2445.95   0

M1(AVE)= 2445.94    M1(CØRR)=  2448.81


 I   TCAL2   TCAL4   TCAL5   AVG T   PCAL      MASS      %DEV
 1   XXXXX   74.41   74.79   74.6    791.936   1232.25    0.006
 2   XXXXX   74.42   74.78   74.6    791.847   1232.11   -0.006

M2(AVE)= 1232.18    M2(CØRR)=  1233.57

TIMERS: 1 = 5962.92    2 = 5962.97    3 = 5962.87    4 = 5962.86

TIME:  5962.91  SECØNDS    MASS FLØW RATE:  0.203799  PØUNDS/SECØND

BARØMETRIC PRESSURE:  12.157  PSIA
---------------------------------------------------------------------

NØZZLE:  0.125     THRØAT DIAMETER:  0.125  INCHES

P START= 703.395    P STØP= 703.395
P MIN= 703.395      P MAX= 703.395     P AVE= 703.395  715.552  PSIA

T START= 76.7   T STØP= 72.5
T MIN=   72.5   T MAX=  76.7   T AVE= 74.2646 DEG F     533.955 DEG R

MASS FLØW RATE:  0.203722  PØUNDS PER SECØND

Z= 0.9887   VO= 1.024E-6   CO= 0.5425   R= 2025570.   C= 0.98848
```

```
Least-squares fit of equation of the form C = A + B/sqr(R)
where C is the discharge coefficient and R is the Reynolds number

DATA FILE: 2RNBS

Number of data points: 12

C= 0.982698 + 8.29 /sqr(R)

Percent Standard Deviation: 0.0207053

 L     Rey No         Cd         Cd(calc)   % Dev
-----------------------------------------------
  1    1.7268 E+6    0.98872   0.98901   -0.029
  2    1.7361 E+6    0.98930   0.98899    0.031
  3    1.8721 E+6    0.98871   0.98876   -0.005
  4    1.8801 E+6    0.98862   0.98874   -0.013
  5    2.0297 E+6    0.98848   0.98852   -0.004
  6    2.0425 E+6    0.98864   0.98850    0.014
  7    2.1462 E+6    0.98861   0.98836    0.026
  8    2.1562 E+6    0.98821   0.98834   -0.014
  9    2.2858 E+6    0.98849   0.98818    0.031
 10    2.2985 E+6    0.98793   0.98817   -0.024
 11    2.4290 E+6    0.98794   0.98802   -0.008
 12    2.4377 E+6    0.98794   0.98801   -0.007
```


Calibration of an NGPLA Venturi
Throat diameter: 0.125 inches
○ 84NBS37, 16 Aug 84
☐ 84NBS39, 17 Aug 84
● Primary point
0.992
0.990
0.988
0.986
0.984
Coefficient of Discharge
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
Throat Reynolds Number / 1E6

Appendix G

Archival Database Structure and Format

The raw data was stored on magnetic tape to provide an archival record. The files on the tape are arranged in the following order.

1. A copy of this document giving the structure of the tape. This file is reproduced in ASCII form.

2. A copy of the test run inventory given in table 27 of this report, also reproduced in ASCII form.

3. The data collected. Certain of the data files contain coefficients for the pressure transducers.

Generally the database is arranged with the pressure transducer response coefficients as the first file. It is followed by a file containing the PRT coefficients. These are followed by four files containing the test run data for all runs taken on each meter tube in the order FE-7ABC, PE-8ABC, FE-9ABC, and FE-0ABC. These files are followed by several auxiliary files as described below.

Database Record Structures

1. Pressure transducer calibration coefficient data blocks.

The coefficient data necessary to convert the recorded pressure transducer readings to pressure units are recorded in a series of 13 record pairs. The format of each record pair is given here:

Record # or description	Columns	Format	Comments
record I			
transducer serial number	1 - 6	XXXXXX	
	7 - 13	blank	
recording date	14 - 21	MM/DD/YY	
	22	blank	
recording time	23 - 30	HH:MM:SS	
	31 - 80	blank	
record II			
constant term	1 - 16	+N.NNNNNNNNNE+NN	
linear term	17 - 32	+N.NNNNNNNNNE+NN	
quadratic term	33 - 48	+N.NNNNNNNNNE+NN	
cubic term	49 - 64	+N.NNNNNNNNNE+NN	
residual standard deviation of the fit	65 - 80	+N.NNNNNNNNNE+NN	

2. Platinum resistance thermometer calibration coefficient data blocks.

The coefficient data necessary to convert the recorded voltage readings into temperature units are recorded as a series of five records, ordered as follows:

i) Orifice thermometer
ii) Nozzle 1 thermometer
iii) Nozzle 2 thermometer
iv) Nozzle 3 thermometer
v) Nozzle 4 thermometer

The format of the records is given here:

Record # or description	Columns	Format	Comments
record I			
PRT ID/Location	1 - 11	XXXXXXXXXXX	
	12	blank	
Constant coefficient	13 - 19	+NNN.NN	
	20	blank	
Linear coefficient	21 - 27	+NNN.NN	

3. Test run header data block.

The header data or those data occurring once in a test run are recorded in a record pair. The format of the records is given here:

Record # or description	Columns	Format	Comments
record I			
run number	1 - 4	NNNN	
	5	blank	
number of pressure records	6 - 9	NNNN	
	10	blank	
date	11 - 18	MM/DD/YY	
	19	blank	
time	20 - 27	HH:MM:SS	
	28	blank	
nozzle 1 diameter (in.)	29 - 34	N.NNNN	If any nozzle field contains 0.0000, then the nozzle was not in operation in the test run.
	35	blank	
nozzle 2 diameter (in.)	36 - 41	N.NNNN	
	42	blank	
nozzle 3 diameter (in.)	43 - 48	N.NNNN	
	49	blank	
nozzle 4 diameter (in.)	50 - 55	N.NNNN	
	56 - 80	blank	
record II			
plate identification	1 - 9	XXXXXXXXX	
	10	blank	
plate diameter (in.)	11 - 16	N.NNNN	
	17	blank	
tube identification	18 - 24	XXXXXXX	
	25	blank	
tube diameter (in.)	26 - 32	NN.NNNN	
	33	blank	
barometric pressure (psia)	34 - 38	NN.NN	
	39 - 80	blank	

4. Pressure and temperature raw data blocks.

The pressure and temperature data are recorded in 5 record blocks. The number of sets is given in the header block as the number of pressure records. The format of the record sets is as follows:

Record # or description	Columns	Format	Comments
record I			
run number	1 - 4	NNNN	
	5	blank	
date	6 - 13	MM/DD/YY	
	14	blank	
time	15 - 22	HH:MM:SS	
	23	blank	
CH0 pressure transducer reading (volts)	24 - 35	+N.NNNNNE+NN	
	36 - 80	blank	
record II			
CH1 pressure transducer reading (volts)	1 - 12	+N.NNNNNE+NN	
CH2 pressure transducer reading (volts)	13 - 24	+N.NNNNNE+NN	
CH3 pressure transducer reading (volts)	25 - 36	+N.NNNNNE+NN	
CH4 pressure transducer reading (volts)	37 - 48	+N.NNNNNE+NN	
CH5 pressure transducer reading (volts)	49 - 60	+N.NNNNNE+NN	
CH6 pressure transducer reading (volts)	61 - 72	+N.NNNNNE+NN	
	73 - 80	blank	

Record # or description	Columns	Format	Comments
record III			
CH7 pressure transducer reading (volts)	1 - 12	+N.NNNNNE+NN	
CH8 pressure transducer reading (volts)	13 - 24	+N.NNNNNE+NN	
CH9 pressure transducer reading (volts)	25 - 36	+N.NNNNNE+NN	
CH10 pressure transducer reading (volts)	37 - 48	+N.NNNNNE+NN	
CH11 pressure transducer reading (volts)	49 - 60	+N.NNNNNE+NN	
CH12 pressure transducer reading (volts)	61 - 72	+N.NNNNNE+NN	
	73 - 80	blank	
record IV			
PRT1 forward temperature reading (volts)	1 - 12	+N.NNNNNE+NN	
PRT2 forward temperature reading (volts)	13 - 24	+N.NNNNNE+NN	
PRT3 forward temperature reading (volts)	25 - 36	+N.NNNNNE+NN	
PRT4 forward temperature reading (volts)	37 - 48	+N.NNNNNE+NN	
PRT5 forward temperature reading (volts)	49 - 60	+N.NNNNNE+NN	
PRT1 reverse temperature reading (volts)	61 - 72	+N.NNNNNE+NN	
	73 - 80	blank	
record V			
PRT2 reverse temperature reading (volts)	1 - 12	+N.NNNNNE+NN	

PRT3 reverse temperature reading (volts)	13 - 24	+N.NNNNNE+NN
PRT4 reverse temperature reading (volts)	25 - 36	+N.NNNNNE+NN
PRT5 reverse temperature reading (volts)	37 - 48	+N.NNNNNE+NN
check resistor forward voltage	49 - 60	+N.NNNNNE+NN
check resistor reverse voltage	61 - 72	+N.NNNNNE+NN
	73 - 80	blank

5. Natural gas composition data blocks.

The data recorded by the on-line chromatographic system at Joliet are stored in a record pair. In many cases, there was not an analysis performed by the chromatograph for each test run. Typically, two test runs were made for each gas analysis recorded. Thus, the data in this record pair corresponds to the most recent analysis recorded prior to the run time listed in the header block. The format of the record pair is given here:

Record # or description	Columns	Format	Comments
record I			
date	1 - 8	MM/DD/YY	
	9	blank	
run time	10 - 17	HH:MM:SS	
	18	blank	
analysis time	19 - 22	HHMM	
	23	blank	
mode	24 - 27	XXXX	
	28	blank	
alarm	29 - 36	XXXXXXXX	
	37 - 80	blank	
record II			
C6+ mole percent	1 - 7	NNN.NNN	
	8	blank	
nitrogen conc. mole percent	9 - 15	NNN.NNN	
	16	blank	
methane conc. mole percent	17 - 23	NNN.NNN	
	24	blank	
CO_2 conc. mole percent	25 - 31	NNN.NNN	
	32	blank	
ethane conc. mole percent	33 - 39	NNN.NNN	
	40	blank	
propane conc. mole percent	41 - 47	NNN.NNN	
	48	blank	
i-butane conc. mole percent	49 - 55	NNN.NNN	
	56	blank	
n-butane conc. mole percent	57 - 63	NNN.NNN	
	64	blank	
i-pentane conc. mole percent	65 - 71	NNN.NNN	
	72	blank	
n-pentane mole percent	73 - 79	NNN.NNN	
	80	blank	

Format for section IV, auxiliary file, for the High Reynolds Number Data Base Project

For the High Reynolds Number data base, the auxiliary file contains the nozzle calibration coefficients, and the pressure transducer daily calibration data.

1. Sonic nozzle diameter and calibration coefficient data block.

The diameter and calibration coefficient data for the sonic nozzles consists of a series of 11 records. These values were used uniformly throughout the data reduction procedures employed in this project. The format of the sonic nozzle data records is given here:

Record # or description	Columns	Format	Comments
record I			
nozzle diameter	1 - 6	N.NNNN	
	7	blank	
A coefficient	8 - 14	N.NNNNN	
	15	blank	
B coefficient	16 - 22	+NN.NNN	
	23 - 80	blank	

2. Static and differential pressure transducer calibration data blocks.

The pressure transducer calibration data are in the form of a header record followed by a series of single data records. For the differential pressure calibrations, the header record identifies the calibration observation number, date, time, transducer serial numbers for the two transducers, and DDR-6000 serial numbers. The calibration observation number is a sequential number which is one (1) at the beginning of any given day, and is not related to the test run number. The format of the differential pressure header record is given here:

Record # or description	Columns	Format	Comments
record I			
calibration observation number	1-2	NN	
	3	blank	
date	4 - 11	MM/DD/YY	
	12	blank	
time	13 - 20	HH:MM:SS	
	21	blank	
DP1 serial number	22 - 27	XXXXXX	
	28	blank	
DP2 serial number	29 - 34	XXXXXX	
	35	blank	
number of data points	36 - 37	NN	
	38 - 80	blank	

The differential pressure data records for the calibration are a series of records containing the DDR-6000 zero and response values, and the response values for each device. The total number of records in the series is given in the header record, above. The format of the data records is given here:

Record # or description	Columns	Format	Comments
record I			
DDR-6000 zero voltage	1 - 9	N.NNNNNNN	
	10	blank	
DDR-6000 response voltage	11 - 18	N.NNNNNN	
	19	blank	
DP1 response voltage	20 - 26	N.NNNNN	
	27	blank	
DP2 response voltage	28 - 34	N.NNNNN	
	35 - 80	blank	

For the static pressure calibrations, the header record identifies the calibration observation number, date, time, barometric pressure, the serial number of the dead weight tester, the serial number of five transducers, and the number of data records in the calibration. The calibration observation number is a sequential number which is one (1) at the beginning of any given day, and is not related to the test run number. The format of the static pressure header record is given here:

Record # or description	Columns	Format	Comments
record I			
calibration observation number	1 - 2	NN	
	3	blank	
date	4 - 11	MM/DD/YY	
	12	blank	
time	13 - 20	HH:MM:SS	
	21	blank	
barometric pressure (psia)	22 - 28	NNN.NNN	
	29	blank	
DWT serial number	30 - 34	XXXXX	
	35	blank	
SP1 serial number	36 - 41	XXXXXX	
	42	blank	
SP2 serial number	43 - 48	XXXXXX	
	49	blank	
SP3 serial number	50 - 55	XXXXXX	
	56	blank	
SP4 serial number	57 - 62	XXXXXX	
	63	blank	
SP5 serial number	64 - 69	XXXXXX	
	70	blank	
number of data records	71 - 72	NN	
	73 - 80	blank	

The static pressure calibration data records are a series of records containing the dead weight tester temperature, carrier mass, total mass, and static pressure, and the response values for each of the five transducers. The format of the data records is given here:

Record # or description	Columns	Format	Comments
record I			
DWT temperature (deg. F)	1 - 7	NN.NNNN	
	8	blank	
DWT weight carrier mass (lb_m)	9 - 16	NN.NNNNN	
	17	blank	
DWT total mass (lb_m)	18 - 24	NNN.NNN	
	25	blank	
DWT static pressure (psig)	26 - 32	NNN.NNN	
	33	blank	
SP1 response voltage	34 - 40	N.NNNNN	
	41	blank	
SP2 response voltage	42 - 48	N.NNNNN	
	49	blank	
SP3 response voltage	50 - 56	N.NNNNN	
	57	blank	
SP4 response voltage	58 - 64	N.NNNNN	
	65	blank	
SP5 response voltage	66 - 72	N.NNNNN	
	73 - 80	blank	

APPENDIX H

Operating Procedure for NGPLA

START UP - Gas in flow meters at line pressure.

In Computer Room:

1. Turn on Kepco Power Supply (it should indicate 30 volts).
2. Check that Ruska DDR6000 is on (3 hour warm-up required).
3. Turn on HP 3497A data logger.
4. Turn on window volt meter.

In Transducer Room:

5. Check that all side valves on the DP transducer 5 ways are closed and all left hand side valves on the static transducer 5 ways are closed.

6a. Close all vents on static transducer 5 ways and open both small valves.

6b. Open right hand side valves on static transducer 5 ways.

6c. Check to make sure 3 small valves on all DP transducer 5 ways are closed. If these valves are closed and DP transducers were left with 600 psi nitrogen gas, skip to step 10. SEE NOTE AT END OF SHUT DOWN PROCEDURE.

7. Close the Whitey vent valve on DDR 5 way.
8. Open the three small valves on the DDR 5 way.
9. Open the side valves on the DDR 5 way.
10. Open pressure pump bypass (pull out little knob).
11. Back out pressure pump counter clockwise. (Return two turns clockwise).
12. Back off N_2 supply regulator at bottle valve for DP calibration.
13. Open N_2 supply valve for DP transducer calibration (lowest Whitey).
14. At N_2 supply regulator open bottle valve and slowly apply pressure (100 psi/10 sec.) to equal gas line pressure.

In Computer Room:

15. Turn on computer power (CRT and printer power also come on). Enter "B:<cr>" at CRT.

16. Punch the "Online Fault" button on the printer (green indicator light comes on).

17. Enter "DO NGPL<cr>" at CRT (computer will display menu).

    NOTE*: At any time during the day, the test loop pressure and temperature values may be monitored from the menu. Enter "1<cr>" at CRT to enter the monitor program.

To Calibrate the Pressure Transducer:

18. Enter "2<cr>" at CRT.

    Computer will display the last ENCAL analysis.
    NOTE: If this does not occur within three minutes, punch "RESET" on computer and go to step 17.

19. Follow the instruction on the CRT.

    NOTE*: The low range DP transducers are calibrated first, then the high range, then the static transducers.

20. Zero differential is taken as valves are now set.

21. To get the requested differential pressure, close the right hand small valve on the DDR 5 way 3 and push in pump bypass knob, adjust the pump as required.

    NOTE: Don't drive the window volt meter negative BELOW its zero DP reading.

22. At the end of each DP transducer calibration open the DDR 5 way right hand small valve and pull out the bypass knob to get zero DP reading. Back out pressure pump (counter clockwise) between DP calibrations and after last DP calibration. Turn pump back clockwise two turns from stop.

23. At the end of each calibration the computer displays and prints calibration data. Keep these prints.

    NOTE*: If the standard deviation on the print-out is:

Low range DP:	greater than .001
High range DP:	greater than .01
Static pressures:	greater than .6

    the calibration must be rerun.

    To rerun enter N when asked "if the calibration was NOT good and you wish to redo it enter N else enter Y".

24. After calibrations are completed the computer returns to the menu.

IMPORTANT--IN TRANSDUCER ROOM - BEFORE YOU PROCEED

25. Close side valves on DDR 5 way. Close valve at N2 regulator.

25a. Very slowly open vent valve 1.

26. Open 2 small valves on any DP transducer 5 way, leave vent closed.

27. When the gas line is to pressure - open both side valves on all DP transducer 5 ways.

28. Close right hand side valves on all static transducer 5 ways.

28a. Close left small valves on static transducer 5 ways.

29. Close 2 small valves opened in step 26.

30. Open left hand side valves on all static transducer 5 ways.

31. Open vents on all static transducer 5 ways.

TRANSDUCERS are ready for data runs.

ORIFICE METER DATA ACQUISITION:

1. When the NGPL menu is displayed after the pressure transducer calibration, enter "3<cr>" at CRT to begin data acquisition.

   NOTE*: Please be certain that the ENCAL is not about to print before this step.

2. The computer will display the last ENCAL analysis. Touch the space bar to continue.

3. The computer will display a message to the operator, followed by the date on which the transducers were last calibrated.

4. The computer will then ask for the next run number, barometric pressure, meter tube designation, orifice plate designation, and each of four nozzle designations. Please follow the instructions on the CRT.

   NOTE*: If a nozzle location is not to be used for the current flowrate, use item #12 for OFF.

5. The computer will then ask for comments from the operator. These comments are particularly useful, for example, to note weather conditions (rain starting during a test point or broken clouds with intermittent sunshine). In addition, the operator should note anything that does not seem appropriate. Note that after all comments have been made, an additional <cr> is required to continue.

6. The pressure and temperature monitor will then be displayed. The operator should wait for stable conditions before beginning data acquisition. If a nozzle which should be OFF has a pressure drop larger than 5 percent, an error message will be displayed. Follow the instructions. If the orifice state pressure falls below 460 psia, the program will abort. If the orifice static pressure falls between 460 and 480 psia, a warning will be displayed. Follow the instructions.

7. Touch the space bar when the cursor is lit to begin data acquisition. Data acquisition requires approximately six minutes.

8. After data acquisition, touch the <cr> to continue. If a new ENCAL analysis is ready, the computer will run the program necessary to read the analysis. Then the data acquisition program will run again. For the same flowrate the program will continue with step #5 of these instructions. After six points at the same flowrate, the program will automatically stop and compute mean pressures, temperatures, mass flowrate, and orifice C_D. Then the data will be put into the database. Wordstar is then used to store operator comments (see special instructions on use of Wordstar).

9. A new ENCAL analysis will be read before returning to the main MENU.

10. If another flowrate is desired, enter "3<cr>" at CRT.

11. After six (6) flowrates or at the end of the day, it is necessary to get a final ENCAL analysis, back up all data on two (2) floppy diskettes, initialize the NGPL database files and put the computer in remote mode for data transmissions. Enter "4<cr>" at CRT to begin these tasks.

    NOTE*: Please be certain that the final ENCAL analysis is later than the one previously used for data acquisition. If necessary, please wait (up to 13 minutes) before entering "4<cr>" at CRT.

SHUT DOWN - Procedures for Transducers After Completion of Daily Runs

In Computer Room:

1. Turn off computer.

2. Turn off window volt meter.

3. IF YOU INTEND TO RUN TOMORROW - leave Kepco on - otherwise turn it off.

In Transducer Room:

4. Close all left hand static pressure 5 way valves.

5. Open two small valves on any DP transducer 5 way, leave vent closed.

6. Close both side valves on all DP transducer 5 ways.

7. Open vent at 5 way used in step 5 (bleed off gas).

8. Close valves opened in step 5 and 7.

9. Check that 3 small valves on DDR 5 way are open.

10. Close Whitey vent at DDR 5 way.

11. SLOWLY open side valves on DDR 5 way.

11a. Slowly open valve at N2 regulator to fill system with N2 to 600 psi.

12. When DP manifold is to 600 psi as set at N_2 regulator, close bottle valve.

    NOTE*: It is important to leave about 600 psi on DP manifold and DDR as applying this pressure just prior to calibration can cause considerable instability during the calibration of DP transducers.

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** *(See instructions)*	1. PUBLICATION OR REPORT NO. NIST/TN-1270	2. Performing Organ. Report No.	3. Publication Date September 1989

4. TITLE AND SUBTITLE

Measurements of Coefficients of Discharge for Concentric, Flange-Tapped, Square-Edged Orifice Meters in Natural Gas Over the Reynolds Number Range 25,000 to 16,000,000

5. AUTHOR(S)

James R. Whetstone, William G. Cleveland, Blaine R. Bateman, Charles F. Sindt

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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American Petroleum Institute
1220 L Street, NW
Washington, DC 20005

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)*

This report describes the data acquisition systems and procedures used in the American Petroleum Institute (API)-sponsored orifice discharge coefficient project performed in natural gas flows and conducted at the test loop of the Natural Gas Pipeline Company of America (NGPL) in Joliet, Illinois. These systems follow the general design philosophy of the companion intermediate Reynolds number project conducted in water flows [1]. NBS provided the measurement and data acquisition systems, maintained the resulting database, and calculated the results from that database.

Measurements of orifice discharge coefficients for 6- and 10-inch diameter orifice meter runs were made using critical venturis for mass flowrate measurement with associated measurement of pressures and temperatures. Eleven venturis were calibrated at the Colorado Engineering Experiment Station, Inc. (CEESI). Measurements of absolute and differential pressure and temperature for venturi and orifice meter conditions were made using an automated data acquisition system. Temperature and pressure measurements were directly related to U.S. national measurement standards. Daily calibration of absolute and differential pressure transducers using pressure working standards was designed into the measurement procedures.

Natural gas compositions were measured using on-line gas chromatography based on gravimetrically-prepared gas standards having compositions closely similar to those of the two gas stream compositions used. Calculations of natural gas density and viscosity were made using a recently developed state-of-the-art equation of state [2] and a corresponding-states model of transport properties [3].

Collected over a 2-year period, the database contains tests on 44 orifice plates in 8 beta ratios for two meter sizes (6- and 10-inches). The database contains 1,345 valid test points.

NOTE: On August 23, 1988 with the signing of the Omnibus Trade and Competitiveness Act, the National Bureau of Standards (NBS) became the National Institute of Standards and Technology (NIST). Since this report was written and reviewed before this change, references to NBS in the body of the report have not been changed to NIST.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Orifice discharge coefficient; natural gas metering

13. AVAILABILITY

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